SPGR Sub-Project Completion Report

Application of GIS for Farm Productivity Enhancement through Land Suitability Assessment of Major Cropping Pattern of Bangladesh

April 2011 to November 2014

Computer & GIS Unit
Bangladesh Agricultural Research Council (BARC)

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PREFACE

Against the backdrop of land scarcity of the country, the investigation under the PIU-BARC funded SPGR sub-project, was carried out as a pilot study to assess the land potential under different crops/cropping pattern of the country in selected locations. The purpose was to develop a method to optimize land utilization through GIS based technology at the upazila level. The work is of much importance; as currently the country is facing many different challenges to elevate productivity and to sustain growth in feeding the increasing population.

By fulfilling the sub-project objective, the desired Crop Suitability Assessment Model (CSAM) software has been developed. The software can be used by the agricultural scientists, extensionists, planners, decision makers and farmers in optimizing land resources utilization and thereby increase production and maximize the benefits. The software is a comprehensive land type updating tool; with scope to generate land type using the DEM and crop suitability maps as well. Further, the user may opt to derive economically best suitable cropping pattern to get the best out of land utilization. The farmers will be the primary beneficiary from the findings of the sub-project- besides the various agricultural R&D practitioners of the country.

Prior to up-scaling of the CSAM software, validation programme to be drawn in all the 30 agro-ecological zones (AEZs). The tool could further be refined and improved based on the field validation and users response. After validating CSAM model can be installed at different upazila agriculture offices of the country for wider adoption and use. Conduction of ToT in this regard may be initiated by BARC followed by series of field level capacity building programme by the DAE.

All our gratefulness to the BARC authority for allowing us to conduct the investigation and to the PIU-BARC for providing required monetary and other support. The Center for Environmental and Geographic Information Services (CEGIS) deserves much thanks for carrying out the field survey and development of the CSAM software. The help and cooperation extended by different stakeholder organizations, individuals, colleagues and support staff towards successful implementation of the project is duly recognized and highly appreciated.

Md. Abeed Hossain Chowdhury
Principal Investigator and
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Abbreviations and Acronyms

AEZ	=	Agro- Ecological Zone
ArcGIS	=	ArcGIS is a geographic information system
ARIS	=	Agricultural Resources Information System
BADC	=	Bangladesh Agricultural Development Corporation
BARC	=	Bangladesh Agricultural Research Council
BARI	=	Bangladesh Agricultural Research Institute
BBS	=	Bangladesh Bureau of Statistics
BMD	=	Bangladesh Meteorological Department
BRRI	=	Bangladesh Rice Research Institute
BWDB	=	Bangladesh Water Development Board
CEGIS	=	Center for Environmental and Geographic Information Services
CSAM	=	Crop Suitability Assessment Model
DAE	=	Department of Agricultural Extension
DAM	=	Department of Agricultural Marketing
DEM	=	Digital Elevation Model
DFD	=	Data Flow Diagram
FAO	=	Food and Agriculture Organization
GIS	=	Geographic Information System
GUI	=	Graphical User Interface
H	=	Highland
HYV	=	High Yielding Variety
IDW	=	Inverse Distance Weighted
L	=	Lowland
LMU	=	Land Mapping Unit
LS	=	Marginally Suitable
MAT	=	Maximum Attainable Yield
MCE	=	Multi-Criteria Evaluation
MH1	=	Medium Highland 1
MH2	=	Medium Highland 2
MIS	=	Management Information System
ML	=	Medium Lowland
MPO	=	Master Plan Organization
MS	=	Moderately Suitable
NARS	=	National Agricultural Research System
NCA	=	Net Cropped Area
NS	=	Not Suitable
S	=	Suitable
SOLARIS	=	Soil and Land Resource Information System
SQL	=	Structured Query Language
SRDI	=	Soil Resource Development Institute
UAO	=	Upazila Agriculture Officer
UAT	=	User Acceptance Testing
VB	=	Visual Basic
VL	=	Very Lowland
VS	=	Very Suitable

Executive Summary

The aim of this special study was to optimize the present utilization of agricultural lands through GIS based technology. As the lead agency the Bangladesh Agricultural Research Council (BARC) was responsible for developing a model for land suitability assessment and coordinating the study. The Soil Resource Development Institute (SRDI) as an information generating agency and a partner of this study was responsible for providing updated soil and land data. As per project provision, BARC engaged the Center for Environmental and Geographic Information Services (CEGIS) though outsourcing to conduct the following components under this study: (i) Baseline survey of the study areas and (ii) Development of GIS based tools (software) for land suitability assessment. In close coordination and logistic support from BARC, CEGIS conducted activities in accordance with the set terms of reference.

The main focus of the baseline survey was to collect base information related to agricultural and socio-economic conditions of selected upazilas and to develop a model for land suitability assessment for 15 major crops of Bangladesh. Eleven upazilas under different agro-ecological regions of the country both under extensive farming practices as well as vulnerable/potential areas were selected for this study. The land suitability of a particular land for growing a specific crop/cropping pattern was assessed through bio-physical and socio-economic conditions. This has been done by considering the degrees to which these environments limit the growth and potential yields of the crop during its normal growing season. Six upazilas namely; Parbatipur, Ghatail, Tangail Sadar, Laksam, Mollahat, and Bagher Para from five districts were selected in the first slot for study. Later on five more upazilas namely; Gangachara, Jagannathpur, Nachole, Nakla and Noakhali Sadar from five districts were selected in the second slot for the study. Databases on agricultural and socio-economic condition of 320 farmers in eleven selected upazilas have been generated through baseline survey. Also databases on land and soil, climatic parameters of 11 upazilas and benefit cost for 15 crops have been created.

During the baseline survey more than 60% of the respondent farmers reported that labour hiring cost was high to very high during both the sowing and harvest periods. About 95% of the farmers thought that the cost of production was high to very high. Furthermore, according to 71% of the respondent farmers the capital intensive technology cost was high to very high. The baseline survey also showed that more than 55% of the farmers have a household with 4 to 6 members, 28% have 7 to 10 members, 9% have 10 or more members, and only 7% have 1 to 3 members in their households. The information collected from the study areas was integrated into the relevant databases for crop suitability assessment. While conducting the baseline survey in the study areas the land type maps prepared using new methodology developed under the study were validated in 320 spots of the selected survey locations. During validation it was found that the land types of most of the survey locations matched with the updated map produced by the software. However, some minor deviations were observed in a few places.

A comprehensive crop suitability assessment framework has been developed, including different important processes of land type updating, edaphic suitability analysis, agro-climate suitability analysis, combined suitability (edaphic+ agro-climatic) analysis, benefit cost ratio of individual crops, major cropping pattern analysis, benefit cost ratio of major cropping patterns, and overall economic suitability of major cropping patterns. The edaphic and agro-climatic suitability was determined based on soil/land and climate factors. Scientific judgments as well as expert knowledge on limiting factors to crop growth were used for the suitability assessment.

To accomplish land suitability assessment of major crops/cropping patterns, a user-friendly GIS based Crop Suitability Assessment Model (CSAM) software was developed. The software provides a comprehensive land type updating tool to generate updated land type maps using the DEM. The user will be able to change the parameters and set the options in the CSAM software. Due to its flexibility, the users/scientists will be able to generate crop suitability maps under different options

or field conditions. Upazila wise crop suitability maps and economically best suitable cropping pattern maps can be generated using both crop suitability and benefit cost (B/C) ratio. Economically best suitable cropping pattern map intersected by union (lowest administrative unit) layer and summarized by cropping patterns and by unions allows the user to view the tabular format of economically best suitable cropping pattern by percentage within union level.

The developed methodologies, framework, and the software under the study will benefit the agricultural scientists, extensionists, planners, decision makers and farmers for optimizing the utilization of land resources thereby increasing the production and maximizing the benefits keeping the productivity of land at sustainable level. At national level, the self-sufficiency in food grain production will be sustained through the increase of land productivity. However, the farmers will be the ultimate beneficiaries from the findings of the project.

For sustainable deployment of CSAM, intensive validation programme could be taken up in 30 Agro-ecological zones (AEZs). The tool could be further improved based on country wide field validation results and user response. After validating and successful implementation of CSAM in 30 AEZs, the model can be deployed and replicated at different upazila agriculture offices of the country. Intensive capacity building programme and deployment of the CSAM can be initiated by BARC. Local level deployment of the crop suitability assessment tool will reduce production cost and substantially contribute in farm productivity enhancement.

1. Sub-Project title:

Application of GIS for farm productivity enhancement through land suitability assessment of major cropping pattern of Bangladesh

2. Coordinator/Principal Investigator/Co-principal investigator:

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3. Duration:

From April, 2011 to June, 2014 and extended upto October 2014

4. Date of approval:

12 April 2011

5. Total approved Budget:

Taka13,675,500 (One crore thirty six lakh seventy five thousand and five hundred)
Taka 11,553,350 (BARC Part)
Taka 2,122,150 (SRDI Part)

Total fund received: Taka 11,553,350

Total fund Spent: Taka 11,553,350

6. Justification of undertaking the sub-project:

The gross total area of the country is about 14.8 million, of which 8.4 million is net cultivable area (NCA). Currently, cultivable area is being lost at an alarming rate due to encroachment by settlements, roads, industries, urban and other infrastructure development. However, most of the agricultural lands are utilized for growing more than one crop. Two crops are grown on half of total agricultural lands. Three crops are grown on 13 per cent of these lands. Cropping intensity at national level is about 180%. The increase of crop production is only possible through increasing cropping intensity and raising crop yields. But the situation appears grim as every year we are losing our valuable agricultural lands to meet other demands of the rising population. The national demand for food grain production is increasing every year against the decreasing trend of net cultivable land. This is a big challenge for the nation, which can be met by proper utilization of our agricultural land resource. In doing so, the farmers should be advised in making the right choice of cropping pattern(s) for their land. This would increase the land productivity and benefit the farmers financially.

Therefore, this non-traditional study was under taken with the aim to optimize the utilization of agricultural lands through GIS based technology. The findings of the study will benefit the farmers for optimizing the utilization of land resources thereby increasing the production and maximizing the benefits keeping the productivity of their land at sustainable level. It will also be useful for the agricultural scientists, planners, decision makers in planning and policy making. At national level, the self-sufficiency in food grain production will be sustained through the increase of land productivity. However, the farmers will be ultimate beneficiaries from the findings of the project.

7. Sub-project objectives:

The objective of the sub-project is to provide land use information to different stakeholders on the choice of rotation of their crops that ensures the increase of food production and maximizes the farmer's income. More specifically the project objectives are:

1. Updating and validation of the land/crop suitability database in order to derive appropriate farming practices for sustainable socio-economic condition.
2. Development of a user friendly GIS based tools (software) for land suitability assessment.

8. Methodology followed in conducting research/investigation:

BARC as the lead agency of this study was responsible for the collection of the relevant information generated by the NARS institutions and others organizations and to develop a model for land suitability assessment. The Soil Resource Development Institute as a partner of this study and as a generator of soil and land information was responsible for providing updated soil and land data. As per project provision, BARC outsourced the task to the Center for Environmental and Geographic Information Services (CEGIS), a public trust under the Ministry of Water Resources for carrying out (i) Baseline survey of the study areas and (ii) Development of a user friendly GIS based decision support system (software) for land suitability assessment. Under the overall supervision of BARC logistics were provided to conduct the study. Regular monitoring was done and feedbacks from the lead agency were communicated to the outsourced organization.

For the successful execution of this study a stepwise conceptual methodology was developed. The systematic approaches/steps were: (i) Needs assessment, (ii) Database development through secondary data collection, (iii) Conduct baseline survey and data collection, (iv) Updating of DEM and land type, (v) GIS based multi-layers database development, (vi) satellite image processing and land use mapping, (vii) data analysis and GIS mapping, (vi) assessment of lands/crop suitability through multi-criteria analysis and matrix development and field validation.

Need Assessment/Requirement Analysis

At the very beginning of the work, an initial planning meeting was organized with relevant professionals and officials of BARC, SRDI and CEGIS to understand the specific requirements of the project. Detail data requirement for baseline study, content of the software and its GIS functionality and modules, platform and running options, satellite images to be used for land use mapping and land suitability assessment, etc. were decided in the meeting.

However, the need assessment task was accomplished following different sub-activities: (i) discussion meeting (ii) identification of agencies who are working on agriculture, crop suitability and land use planning related activities, (iii) identification of project need/requirements and (iv) listing of requirements and expected outputs. The summary of these sub-activities are presented diagrammatically in Figure-1 and described below.

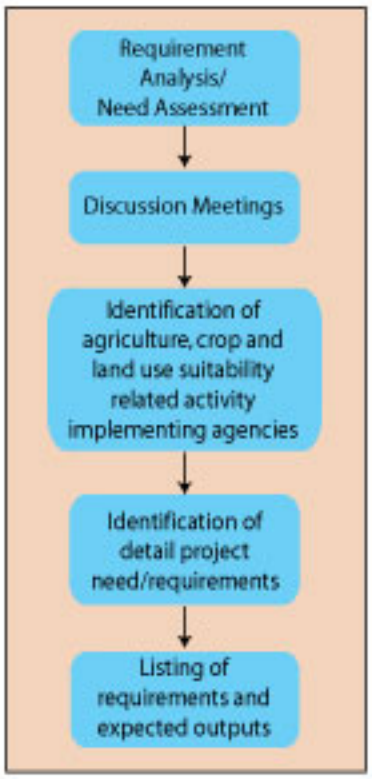


Figure 1. Steps of Requirement Analysis

(i) Organization of discussion meeting

A consultation/discussion meeting was organized at BARC between CEGIS professionals and officials of BARC for assessing the detail project needs/requirements and to prepare the inception report. Expectation from the project, data need, data format, secondary data sources, and framework of the software etc. were discussed during the discussion meeting.

(ii) Identification of agriculture, crop and land use suitability related activity implementing agencies

Different agencies, such as DAE, BARI, BRRI, BADC and SRDI etc., those are involved in crop and land use suitability related activities were consulted. Then types of data and their availability in those organizations were identified and listed and the processes for data collection from those agencies were discussed.

(iii) Identification of detail project need/requirements

Need assessment was done following the project document. The detail requirements were focused on approach of the baseline survey, module and functionality of the GIS based tools/software, satellite images use for land use mapping and land suitability assessment etc. Several relevant projects such as (i) Assessment of land use (physical and economic) suitability of coastal areas of Bangladesh (ii) Updating the AEZ (Agro ecological Zones) database (Climatic Parameters) and (iii) Agricultural Resources Information System (ARIS) Tools (iv) Soil and Land Resource Information System (SOLARIS) (v) Application of Agro-ecological Zones Database in Drought Management and Water Availability Assessment etc. were explored to fulfill the requirements of the sub-project including GIS based tools development. Finally, the experience and knowledge gathered from these projects were capitalized for assessing the need of this sub-project.

(iv) listing of requirements and expected outputs

Expected outputs from this project was decided through consultation meeting and as well as individual consultation with relevant officials of NARS institutes and different stakeholder. The major expected outputs are: updated DEM, updated land type maps, crop suitability assessment framework/criteria including socio-economic parameters, updated land use and crop suitability maps for the study upazilas. All these expected outputs were listed and documented.

Identification and collection of data from secondary sources

Identification and collection of data from secondary sources was one of the major tasks of this project. The list of secondary data sources and their detail information used for this study is given in the Table 1.

Table1. List of Secondary Data Sources and Their Detail Information Used for the Study

Data Source	Data type
SRDI	All updated data of soil & land resource/type/use
BARC	Crop suitability maps, land resources data
DAE	Agricultural data (area under cultivation, yields of crops, etc.)
DAM	Market price information of crops
BMD	Climate data
BBS	Agricultural, census, market data and socio-economic data
CEGIS	Related & available data from NWRD data, satellite images, land use maps etc.

Available literature related to agriculture, agricultural land use and crop suitability assessment were collected, especially from SRDI, BARC and DAE and thoroughly reviewed to fulfill the project objectives.

The land resources related activity in Bangladesh was initiated in 1979 under the FAO/UNDP Land Use Advisory Project to make reconnaissance Soil Survey information as a basis for more rational planning of agricultural development. During the period 1980 to 1987 a national Agro ecological Zones (AEZ) based computerized land resources database system was successfully developed. This physical resources database on land, soils, climates, hydrology and land suitability was used for national and sub-national agricultural research and development planning. During this period several reports were prepared and some of the important reports are; (i) Report 2: Land Resources Appraisal of Bangladesh for agricultural development focus on Agro-ecological Regions of Bangladesh; (ii) Report 6: Land Resources Appraisal of Bangladesh for agricultural development focus on Land Suitability. This physical land resources database contains the information on land, soils, climates, hydrology and land suitability under 30 agro-ecological zones.

The AEZ system maintained at BARC is used in generating readily accessible and transferable information on biophysical resources, especially for researchers, extension personnel and decision makers in land and agricultural resources management and agricultural development planning. However, it was felt that considering only physical parameters in planning exercises is not adequate in addressing the intricacies of resource planning under the complex Bangladesh environmental conditions.

Geographic Information System was established at BARC with UNDP assistance during the period 1996-2001 under a project entitled "Utilization of Agro ecological Zones Database and Installation of GIS for Agricultural Development". Through this project all previous data were transformed into a GIS based database.

Further to this agro-climatic parameter of the database was updated by BARC with technical assistance from CEGIS under financial assistance of FAO during 2008. All these reports and information have been thoroughly reviewed for the successful implementation of this study.

Then the, SRDI information has been reviewed to prepare an updated database for this study. SRDI has developed a GIS based Soil Resources Information System (SOLARIS) with technical assistance from CEGIS. This SOLARIS database has been explored in detail for this study. Besides, different database and MIS related to agriculture and crop/land use developed by other organizations such as (i) National Fisheries Database, (ii) Sundarbans Fisheries Database, (iii) Shrimp Crop DSS, (iv) National Water Resources Database (NWRD) and (v) Integrated Coastal Resources Database (ICRD), and Agricultural Resources Information System (ARIS) were also been reviewed for smooth and efficient project implementation.

Selection of study area and survey location

Based on the expert opinion and several agro-environmental, vulnerability and socio-economic criteria the study area and survey location were selected. The specific criteria followed for selecting the study areas are given below:

a. Major agro-ecological regions
b. Extensive farming practices
c. Potential vulnerable areas due to agricultural constrain (e.g. drought, flood, river erosion, salinity etc.)
d. Physical characteristics of the study area including water availability and soil condition
e. Agricultural characteristics including land type, land use and cropping pattern
f. Socio-economic parameters including transportation and marketing facilities etc.

Description of the Study Area

Geographical location and demography

Six upazilas namely; Parbatipur, Ghatail, Tangail Sadar, Laksam, Mollahat, and Bagher Para from five districts were selected in the first slot for study. Later on five more upazilas (second slot) were added to this study. The upazilas are Gangachara, Jagannathpur, Nachole, Nakla and Noakhali Sadar. The map of the study areas is presented in Figure 2 and the detail list of selected upazilas are presented in Table 2.

Table 2. List of Selected Upazilas

SI No.	Slot	Division	District	Upazila	Area in ha
1	First	Rangpur	Dinajpur	Parbatipur	42728
2		Dhaka	Tangail	Ghatail	45057
3		Dhaka	Tangail	Tangail Sadar	30564
4		Chittagong	Comilla	Laksam	43252
5		Khulna	Bagerhat	Mollahat	21753
6		Khulna	Jessore	Bagher Para	27208
7	Second	Dhaka	Sherpur	Nakla	17359
8		Chittagong	Noakhali	Noakhali Sadar	110850
9		Rajshahi	Nawabganj	Nachole	29266
10		Rangpur	Rangpur	Gangachara	21492
11		Sylhet	Sunamganj	Jagannathpur	36505

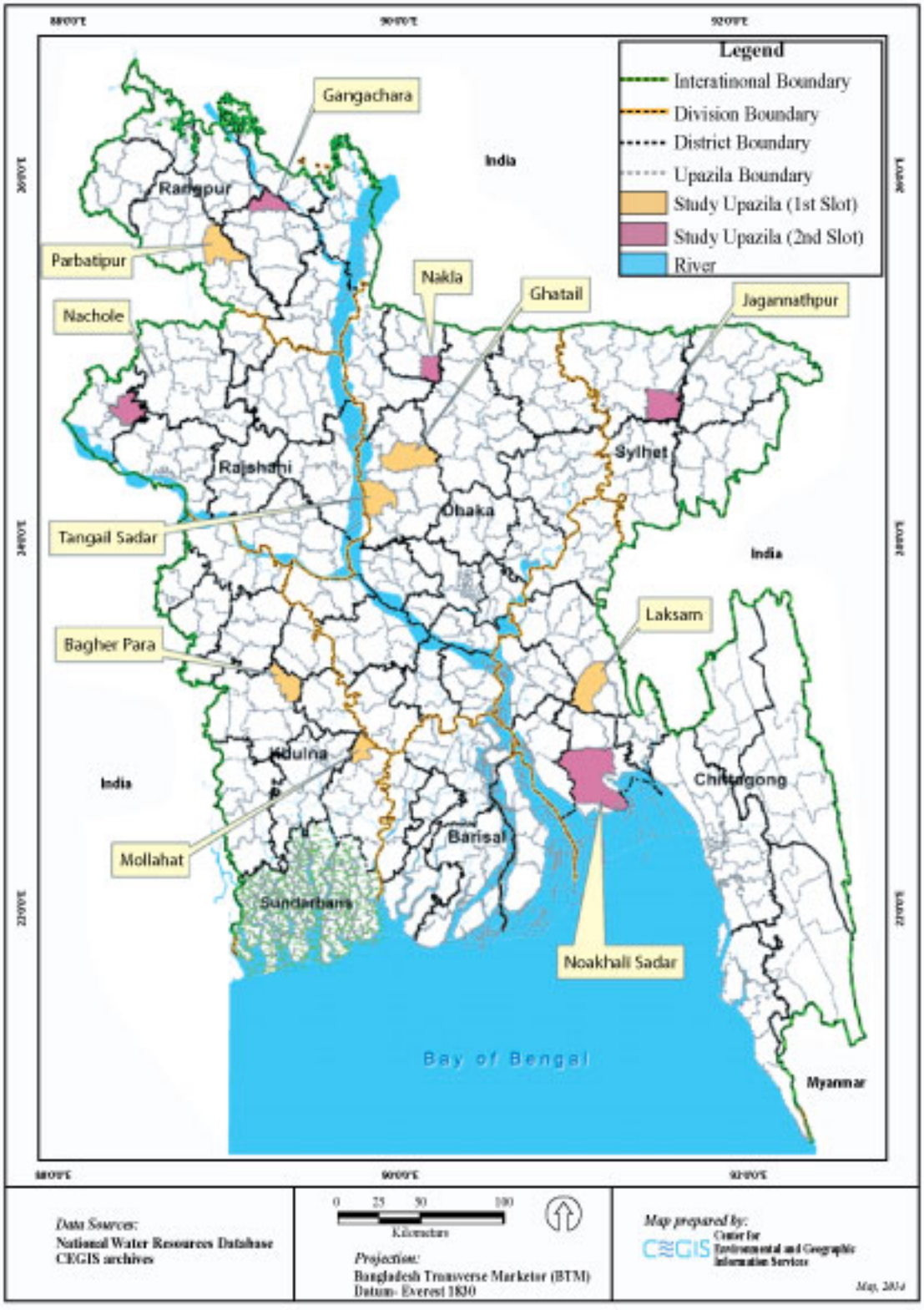


Figure 2. Location Map of study area (Upazilas)

Agro-Ecological Zone (AEZ)

The agro-ecological zones of Bangladesh are characterized based on the combinations of soil, landform, hydrology and climatic parameters. Each zone is characterized by a set of constraints and potentials for land use. Land areas are recognized on the basis of hydrology, physiography, soil types, tidal activity, cropping patterns, and seasons. In fact, an agro-ecological zone indicates an area characterized by homogeneous agricultural and ecological characteristics. Thirty agro-ecological zones has been recognized in Bangladesh. Although there are 30 AEZs, only 18 fall in the selected upazilas. The agro-ecological zones within the selected upazilas are described below in brief. The list of identified AEZs with their locations is presented in Table 3 (Figure 3). The brief description of different agro-ecological zones within the selected upazilas is given in this section.

Active Tista Floodplain (2): This region includes the active floodplains of the Tista, Dharla and Dudkumar rivers. It has complex patterns of low, generally smooth ridges, inter-ridge depressions, river channels and cut-off channels. Seasonal flooding is mainly shallow, but flooding is occasionally deep during flood peaks. The area has irregular patterns of grey stratified sands and silts. They are moderately acidic throughout and parent alluvium is rich in weatherable minerals. It is neutral to slightly acidic in reaction but not calcareous.

Tista Meander Floodplain (3): The Tista Meander Floodplain region occupies the major part of the Tista floodplain as well as the floodplain of the Atrai, Little Jamuna, Karatoya, Dharla and Dudhkumar rivers. Most areas have broad floodplain ridges and almost level basins. The area is mainly shallowly to moderately flooded. There is an overall pattern of olive brown, rapidly permeable, loamy soils on the floodplain ridges, and grey or dark grey, slowly permeable, heavy silt loam or silty clay loam soils on the lower. Eight general soil types are found in the region, moderately acidic throughout, low in organic matter content on the higher land, but moderate in the lower parts. Fertility level is low to medium. Soils, in general, have good moisture holding capacity.

Active Brahmaputra-Jamuna Floodplain (7): The Active Brahmaputra-Jamuna Floodplain region comprises the belt of unstable alluvial land along the Brahmaputra-Jamuna rivers where land is constantly being formed and eroded by shifting river channels. It has an irregular relief of broad and narrow ridges and depressions. The area is occupied by sandy and silty alluvium, rich in weatherable Potassium bearing minerals that are slightly alkaline in reaction. Six general soil types occupy the area. Organic matter status is low and fertility status is low to medium.

Young Brahmaputra and Jamuna Floodplain (8): The Young Brahmaputra and Jamuna Floodplain region comprises the area of Brahmaputra sediments. It has a complex relief of broad and narrow ridges, inter-ridge depressions, partially in filled cut-off channels and basins. This area is occupied by permeable silt loam to silty clay loam soils on the ridges and impermeable clays in the basins, neutral to slightly acid in reaction. General soil types include predominantly grey floodplain soils. Organic matter content is low in ridges and moderate in basins.

Old Brahmaputra Floodplain (9): The Old Brahmaputra Floodplain region occupies a large area of Brahmaputra sediments before the river shifted to its present Jamuna channel about 200 years ago. The region has broad ridges and basins. Relief is irregular, especially near the old and present river channels. The soils of the area are predominantly silt loams to silty clay loams on the ridges and clay in the basins. Organic matter content is low on the ridges and moderate in the basins. Topsoils are moderately acidic but the subsoils are neutral in reaction. General fertility level is low.

High Ganges River Floodplain (11): This region includes the western part of the Ganges River Floodplain which is predominately high land and medium high land. Most areas have a complex relief of broad and narrow ridges and inter-ridge depressions, separated by areas with smooth broad ridges and basins. The upper parts of high ridges stand above normal flood level. Lower parts of ridges and basin margins are seasonally shallowly flooded. There is an overall pattern of olive-brown silt loams and silty clay loams on the upper parts of the floodplain ridges and dark grey, mottled brown, mainly clay soils on ridge sites and in basins. Most ridge soils are calcareous throughout.

General soil types predominately include Calcareous Grey Floodplain soils and Calcareous Brown Floodplain soils. Organic matter content in brown ridge soils is low and higher in dark grey soils. Soils are slightly alkaline in reaction. The fertility level is generally low.

Table 3. Agro-ecological zone of the study area

Sl	Division	District	Upazila	Region Name (AEZ Number)	Area (ha)
1	Rangpur	Dinajpur	Parbatipur	Level Barind Tract	16663
				North-eastern Barind Tract	2627
				Tista Meander Floodplain	19367
2	Dhaka	Tangail	Ghatail	Madhupur Tract	21144
				Old Brahmaputra Floodplain	14641
				Young Brahmaputra and Jamuna Floodplains	6339
3	Dhaka	Tangail	Tangail Sadar	Active Brahmaputra-Jamuna Floodplain	13212
				Young Brahmaputra and Jamuna Floodplains	14036
4	Chittagong	Comilla	Laksam	Northern and Eastern Piedmont Plains	598
				Old Meghna Estuarine Floodplain	34675
5	Khulna	Bagerhat	Mollahat	Gopalganj-Khulna Beels	12025
				Low Ganges River Floodplain	8309
6	Khulna	Jessore	Bagher Para	High Ganges River Floodplain	23447
				Low Ganges River Floodplain	1614
7	Rangpur	Rangpur	Gangachara	Active Teesta Floodplain	2467
				Tista Meander Floodplain	15100
8	Rajshahi	Nawabganj	Nachole	High Ganges River Floodplain	2832
				Level Barind Tract	3705
				High Barind Tract	20971
9	Dhaka	Sherpur	Nakla	Young Brahmaputra and Jamuna Floodplain	875
				Old Brahmaputra Floodplain	14715
				Northern and Eastern Piedmont Plains	344
10	Sylhet	Sunamganj	Jagannathpur	Eastern Surma-Kushiyara Floodplain	15038
				Sylhet Basin	17007
				Lower Meghna River Floodplain	1450
11	Chittagong	Noakhali	Noakhali Sadar	Young Meghna Estuarine Floodplain	79164
				Old Meghna Estuarine Floodplain	972

Low Ganges River Floodplain (12): The Lower Ganges River Floodplain region comprises the eastern half of the Ganges river floodplain which is low-lying. The area has a typical meander floodplain landscape of broad ridges and basins. The soils of this region are silt loams and silty clay loams on the ridges and silty clay loam to heavy clays on lower sites. General soil types predominantly include calcareous dark grey and calcareous brown floodplain soils. Organic matter content is low in ridges and moderate in the basins. General fertility level is medium.

Gopalganj-Khulna Beels (14): The Gopalganj-Khulna Beel region occupies extensive low-lying areas between the Ganges River floodplain and the Ganges tidal floodplain. The soils of the area are grey, and dark grey, acidic, heavy clays overlay peat or muck at 25-100 cm. General soil types include mainly peat and non-calcareous dark grey floodplain soils. Organic matter content is medium to high. Fertility level is medium.

Lower Meghna River Floodplain (17): This area occupies transitional area between Middle Meghna River Floodplain and the Young Meghna Estuarine Floodplain. The region has slightly irregular relief, but with little difference in elevation between the ridges and depressions. Soils of this area are relatively uniform, silt loams occupy relatively higher areas and silty clay loams occupy the depressions. Noncalcareous Dark Grey Floodplain and Calcareous Grey Floodplain soils are major components of General Soil Types. Topsoils are moderately acidic and subsoils neutral in reaction. General fertility level is medium to high with low to medium organic matter status and K-bearing minerals.

Young Meghna Estuarine Floodplain (18): This region occupies young alluvium land in and adjoining the Meghna Estuary. It is almost level with very low ridges and broad depressions. The soils of this region are grey to olive, deep, calcareous silt loam and silty clay loams and are stratified either throughout or at shallow depth. Calcareous Alluvium and Non-calcareous Grey Floodplain soils are the dominant general type. The soils of the south become saline in dry season. Top soils and sub-soils of the area are mildly alkaline. General fertility is medium. The content of organic matter is low.

Old Meghna Estuarine Floodplain (19): This region occupies a large area, mainly low-lying between south of the Surma-Kusiyara Floodplain and northern edge of the Young Meghna Estuarine Floodplain. It comprises smooth, almost level, floodplain ridges and shallow basins. Seasonal flooding due to accumulated rainwater. It is moderately deep or deep in the north and west, but it is shallow in the south east. Silty soils predominate on highlands and silty clay to clay in low lands. Noncalcareous Dark Grey Floodplain soils are the only general type of the area. Organic matter content of the soils are moderate. Moisture holding capacity is medium. Topsoils are strongly acidic, but subsoils are neutral in reaction. General fertility level is medium.

Eastern Surma-Kusiyara Floodplain (20): This region occupies the relatively higher parts of the Surma-Kushiyara Floodplain formed on sediments of the rivers draining into the Meghna catchment area from the Northern and Eastern hills. The area is mainly smooth, broad ridges and basins. The whole region is subject to early floods. Ridges are shallowly and basins are deeply flooded. This area is occupied by grey, heavy silty clay loams on the ridges and clays in the basins. Non calcareous Grey Floodplain soils are the only General Soil Type. Organic matter content of the soil is moderate. Soil reaction ranges from strongly acidic to neutral.

Sylhet Basin (21): The region occupies the lower, western side of the Surma-Kushiyara Floodplain. The area is mainly smooth, broad basins with narrow ridges of higher land along rivers. Ridges are shallowly and basins are deeply flooded. Soils of the area are grey silty clay loams and clays on the higher parts that dry out seasonally and grey clays in the wet basins. Non calcareous Grey Floodplain soils and Acid Basin Clays are the major components of the general soil types. The soils have moderate content of organic matter and soil reaction is mainly acidic.

Northern and Eastern Piedmont Plains (22): The Northern and Western Piedmont Plains is a discontinuous region occurring as a narrow strip of land at the foot of the northern and eastern hills. The region comprises of merging alluvial fans which slope gently outward from the foot of the northern and eastern hills into smooth, low-lying basins. Grey piedmont soils and non-calcareous grey floodplain soils are the major general soil types of the area. The soils of the area are loams to clays, slightly acidic to strongly acidic in reaction. The general fertility level is low to medium.

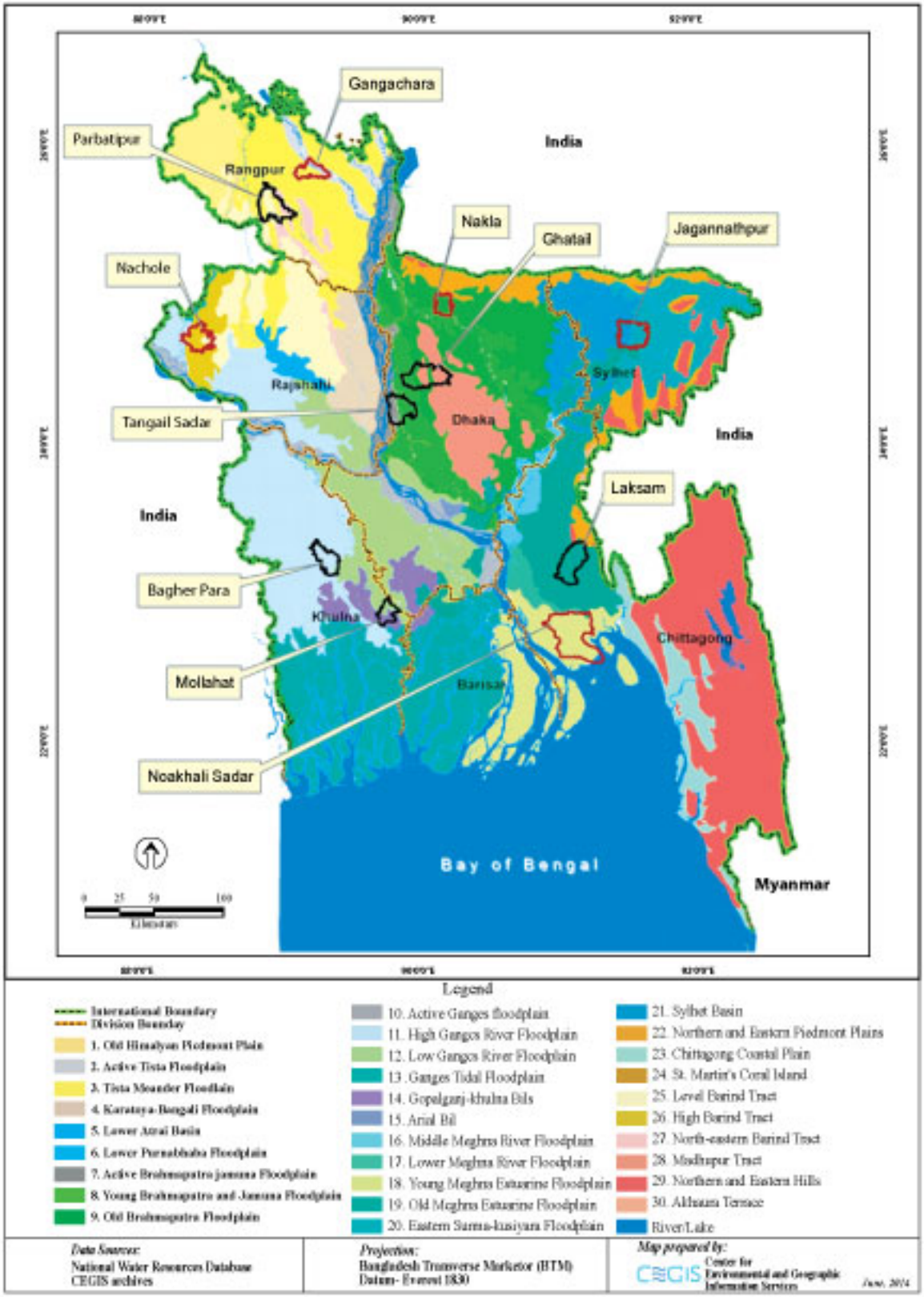


Figure 3. Agro-ecological zones with study locations

Level Barind Tract (25): The Level Barind Tract region is developed over the Madhupur Clay. The landscape is almost level. The predominant soils have grey, silty, puddled topsoil with ploughpan. Shallow grey terrace soil and deep grey terrace soils are the major components of the general soil types of the area. The soils have low moisture holding capacity and slightly acidic to acidic in reaction. Organic matter status is very low and most of the available nutrients are limiting.

High Barind Tract (26): This region includes the western part of Barind Tract where the underlying Madhupur Clay has been uplifted and cut into by deep valleys. The High Barind Tract occupies about 10% of the whole Barind Tract. It is underlaid by heavy Madhupur Clay which often contains large lime nodules. The soils include paddled silt loam to silty clay loam in the topsoils and porous silt loam with mottled plastic clay at varying depth. Deep Grey Terrace soils and Grey Valleys soils are the major components of general soil types of the area. General fertility status is low having low status of organic matter.

North-eastern Barind Tract (27): The North Eastern Barind Tract region occupies several discontinuous areas on the north-eastern margins of the Barind Tract. It has silty or loamy topsoil and clay loams to clay subsoil. The soils are strongly acidic in reaction. Organic matter in the soils is low. General fertility is poor.

Madhupur Tract (28): This is a region of complex relief and soils are developed over the Madhupur Clay. The landscape comprises level upland, closely or broadly dissected terraces associated with either shallow or broad deep valleys. Eleven general soil types exist in the area of which, Deep Red Brown Terrace, Shallow Red Brown Terrace soils and Acid Basin Clays are the major ones. The soils on the terrace are better drained, friable clay loams to clays overlying friable clay substratum at varying depths. The soils in the valleys are dark grey heavy clays. They are strongly acidic in reaction with low status of organic matter, low moisture holding capacity and low fertility level. The soils are mainly phosphate fixing, and low in P, K, S and B levels.

Soil

Soil characteristics play a vital role in selection of crop for production in a specific location/ field. Several parameters lie under the soil characteristics. These are soil association, soil texture, soil structure, moisture pattern, drainage pattern etc. A brief description of the soil characteristics by upazila of the study area were given below:

Parbatipur Upazila: The soils in this upazila are predominantly loam to clay loam in texture. Some loam soils are also found here. The drainage pattern of the soils is imperfectly drained to moderately poor drained. Some soils are poorly drained too. On the other hand, the moisture pattern of the soils is mainly medium to high. Low moisture is also found in the soils of this upazila.

Ghatail Upazila: The major portion of the soils in Ghatail upazila is clay to clay loam in texture with some loam soils. The soils are very poorly to imperfectly drained. The moisture pattern of the soils is mainly medium to high with some low moisture containing soils.

Tangail Sadar Upazila: The major section of the soils in Tangail Sadar upazila is loam in texture. There are also some clay, clay loam and sandy soils. The moisture pattern of the soils is mainly high. Low and medium moisture holding soils is also found in this upazila. The drainage pattern of the soils of the upazila is poorly to imperfectly drained.

Laksam Upazila: The dominant part of the soils of this upazila is clay loam to loam in texture. The moisture pattern of the soils is low to medium. The drainage pattern of the soils of the upazila is poorly drained to imperfectly drained.

Mollahat Upazila: The major part of the soils in this upazila is clay loam to loam in texture with some clay soils. The moisture pattern of the soils is mainly medium to high. However, some soils with low moisture content is also found. The drainage pattern of the soils in Mollahat upazila is very poorly drained to imperfectly drained.

Bagher Para Upazila: The soils in this upazila is dispersed into clay, clay loam and loam in texture. The moisture pattern of the soils is distributed as low, medium and high. The soils of the upazila are very poorly to imperfectly drained.

Gangachara Upazila: The major part of the soils in this upazila is loam to sandy loam in texture with some sandy soils. The moisture pattern of the soils is mainly medium to high. However, some soils with low moisture content is also found. The drainage pattern of the soils in Gangachora upazila is poorly drained to imperfectly drained with some soils which have moderately well drainage capacity.

Nachole Upazila: The major section of the soils in Nachole upazila is clay to clay loam in texture. There are also some loam soils. The moisture pattern of the soils is mainly low. Few high moisture holding soils are also found in this upazila. The drainage pattern of the soils of the upazila is moderately well to imperfectly drained.

Nakla Upazila: The soils in Nakla upazila are predominantly loam to sandy loam in texture. Sandy and clayey soils are also found here in moderate amount. The drainage pattern of the soils is moderately poor drained to poorly drained. Moderately well to very poorly drained soil patterns are also found in some extent. On the other hand, the moisture pattern of the soils is mainly low to medium. High moisture is also found in the soils of this upazila.

Jagannathpur Upazila: The soils in this upazila are predominantly loam to clay loam in texture. Some loam soils are also found here. The drainage pattern of the soils is poorly drained to very poorly drained. On the other hand, the moisture pattern of the soils is mainly medium to high. Low moisture is also found in the soils of this upazila.

Noakhali Sadar Upazila: The dominant part of the soils of this upazila is clay loam to loam in texture. The moisture pattern of the soils is high to medium. The drainage pattern of the soils of the upazila is poorly drained to very poorly drained.

Land Types

The term Land type is used for describing the depth of flooding phases. It also indicates the distribution of land levels in relation to seasonal flooding. In Bangladesh, six basic inundation land types are recognized. They are mainly Highland, Medium Highland1, Medium Highland 2, Medium Lowland, Lowland and Very Lowland. Each land type relates to the normal range of flood depths during the peak rainfall period of the Kharif (wet) season, and corresponds approximately with peak discharges of the river systems. The land type with their inundation level has been presented in Table 4.

Table 4. Land types and description

Code	Land Type	Symbol	Description
1	Highland	H	Land which is above normal inundation level
2	Medium Highland 1	MH1	Land which is normally inundated less than 30 cm deep
3	Medium Highland 2	MH2	Land which normally is inundated in the range 30-90 cm deep
4	Medium Lowland	ML	Land which is normally inundated in the range of 90-180 cm depth
5	Lowland	L	Land which is normally inundated in the range of 180-300 cm depth
6	Very Lowland	VL	Land which is normally inundated more than 300 cm deep

Climate

Geographical location and physical settings govern the climate of a country. Bangladesh is located in the tropical monsoon region and its climate is characterized by high temperature, heavy rainfall, often excessive humidity, and fairly marked seasonal variations. The most striking feature of its

climate is the reversal of the wind circulation between summer and winter, which is an integral part of the circulation system of the South Asian subcontinent (Banglapedia, 2013).

Station-wise climatic data were acquired from Bangladesh Meteorological Department (BMD) for the period from 1980 to 2011. The station-wise data were processed and the upazila wise data were derived by using Theisen method in ArcGIS software. Although the climatic condition all over the country is largely similar, yet there are some variations from place to place. Brief descriptions of the climatic condition of the selected upazilas are presented in Figures 4a and 4b.

Parbatipur Upazila: The average temperature of Parbatipur upazila is 25°C while the average minimum temperature is 16°C and the average maximum temperature is 29°C. The minimum temperature is 7°C found in January and maximum temperature is 37°C found during April, May and June. In Kharif-1 season, the maximum temperature varies between 35°C and 37°C and the minimum temperature varies from 13°C to 22°C. In Kharif-2 season, the maximum temperature varies from 34°C to 36°C and the minimum temperature varies from 18°C to 24°C. In Rabi season, the maximum temperature varies from 27°C to 31°C and the minimum temperature varies from 7°C to 13°C.

The average annual rainfall of this upazila is 2139 mm. The minimum rainfall occurs in December, which is 8 mm and maximum rainfall of 471 mm in July. The maximum rainfall is 386 mm and minimum rainfall is 17 mm in Kharif-1 season. In Kharif-2 season, the maximum rainfall is 471 mm and the minimum rainfall is 166 mm. The maximum and the minimum rainfall are 12 mm and 8 mm respectively in Rabi season. Figure 4a-(i) depicts the monthly climate scenario of Parbatipur Upazila.

Ghatail Upazila: The mean annual temperature of Ghatail upazila is 25°C whereas the average annual minimum and maximum temperatures are 17°C and 29°C respectively. The average monthly minimum temperature is 8°C found in January, while the average monthly maximum temperature is 38°C found in April. The average maximum temperature varies from 36°C to 38°C and 28°C to 32°C in Kharif-1 and Rabi seasons respectively. Again, the average minimum temperature varies from 14°C to 22°C and 8°C to 14°C in Kharif-1 and Rabi season respectively. In Kharif-2 season, the average maximum temperature is 35°C and the minimum temperature varies from 20°C to 24°C.

The total annual rainfall of the Ghatail upazila is 1,909 mm. The minimum monthly total rainfall is 7 mm found in January and monthly maximum total rainfall is 354 mm found in July. The maximum total rainfall is 324 mm, 354 mm, and 28 mm respectively in Kharif-1, Kharif-2 and Rabi seasons. On the other hand, the minimum total rainfall is 46 mm, 173 mm and 7 mm in Kharif-1, Kharif-2 and Rabi seasons respectively. Figure 4a-(ii) shows the monthly climate scenario of Ghatail Upazila.

Tangail Sadar Upazila: The mean annual temperature of Tangail Sadar upazila is 25°C. The average annual minimum and maximum temperature is 17°C and 29°C. The average monthly minimum temperature is 8°C occurs in January and average monthly maximum temperature is 38°C found in April. The average maximum temperature varies between 36°C to 38°C and 28°C to 32°C in Kharif-1 and Rabi seasons respectively. Again, the average minimum temperature varies from 14°C to 22°C and 8°C to 14°C in Kharif-1 and Rabi seasons respectively. Kharif-2 season, the average maximum temperature is 35°C and the minimum average temperature varies from 20°C to 24°C.

The total annual rainfall of the Tangail Sadar upazila is 1868 mm. The minimum monthly total rainfall is 7 mm found in January and maximum monthly total rainfall is 344 mm in July. The maximum total rainfall is 315 mm, 344 mm, and 28 mm in Kharif-1, Kharif-2 and Rabi seasons respectively. The minimum total rainfall is 46 mm, 169 mm and 7 mm in Kharif-1, Kharif-2 and Rabi season respectively. The monthly climate scenario of Tangail Sadar Upazila is presented in Figure 4a(iii).

Laksam Upazila: The mean annual temperature of Laksam upazila is 25°C while the average minimum monthly temperature is 18°C and the average maximum monthly temperature is 28°C. The minimum temperature is 9°C found in January and maximum temperature is 36°C occurs in May. In Kharif-1 season, the maximum temperature varies from 34°C to 36°C and the minimum

temperature varies from 15°C to 23°C. In Kharif-2 season, the maximum temperature varies from 34°C to 35°C and the minimum temperature varies from 20°C to 24°C. The maximum temperature varies from 29°C to 33°C and the minimum temperature varies from 9°C to 15°C in Rabi season.

The total annual rainfall of the Laksam upazila is 2405 mm. The minimum rainfall occurs during December and January, which is 9 mm and maximum rainfall is 508 mm in July. The maximum rainfall is 410 mm and minimum rainfall is 69 mm in Kharif-1 season. In Kharif-2 season, the maximum rainfall is 508 mm and the minimum rainfall is 174 mm. The maximum rainfall is 38 mm and the minimum rainfall is 9 mm in Rabi season. The monthly climate scenario of Tangail Sadar Upazilais presented in Figure 4a-(iv).

Mollahat Upazila: In Mollahat upazila winter starts 15 days later than that from the northern part of Bangladesh. The mean annual temperature of this upazila is 26°C whereas the average annual minimum temperature is 18°C and the average annual maximum temperature is 30°C. The average monthly minimum temperature is 9°C found in January and average monthly maximum temperature is 38°C found in April. The average maximum temperature varies from 37°C to 38°C and 29°C to 33°C in Kharif-1 season and Rabi season respectively. Again, the average minimum temperature varies from 15°C to 23°C and 9°C to 15°C in Kharif-1 season and Rabi season respectively. In Kharif-2 season, the average maximum temperature is 35°C and the minimum temperature varies from 20°C to 24°C.

The annual total rainfall of the Mollahat upazila is 1841 mm. The minimum monthly total rainfall is 7 mm found in December and maximum monthly total rainfall is 344 mm in July. The maximum total rainfall is 341 mm, 344 mm, and 36 mm in Kharif-1, Kharif-2 and Rabi seasons respectively. Oppositely, the minimum total rainfall is 53 mm, 149 mm and 7 mm in Kharif-1, Kharif-2 and Rabi seasons respectively. Figure 4a-(v) shows the monthly climate scenario of Mollahat Upazila.

Bagher Para Upazila: The mean annual temperature of Bagher Para upazila is 26°C where the annual average minimum temperature is 18°C and the annual average maximum temperature is 30°C. The average monthly minimum temperature is 8°C found in January and average monthly maximum temperature is 39°C found during April and May. In Kharif-1 season the average maximum temperature varies from 37°C to 39°C and the average minimum temperature varies from 14°C to 23°C. In Kharif-2 season, the average maximum temperature is 35°C and the average minimum temperature varies from 19°C to 24°C. In Rabi season, the average maximum temperature varies from 29°C to 33°C and the minimum temperature varies from 8°C to 13°C.

The total annual rainfall of the Bagher Para upazila is 1,722 mm. The minimum monthly total rainfall is found in December, which is 13 mm, and maximum monthly total rainfall is 340 mm found in July. The maximum total rainfall is 313 mm and minimum total rainfall is 45 mm in Kharif-1 season. In Kharif-2 season, the maximum total rainfall is 340 mm and the minimum total rainfall is 138 mm. The maximum total rainfall is 31mm and the minimum total rainfall is 13mm in Rabi season. Figure 4a-(vi) depicts the monthly climate scenario of Bagher Para upazila.

Gangachara Upazila: The average annual temperature of Gangachara upazila is 25°C while the average minimum temperature is 20°C and the average maximum temperature is 29°C. The minimum temperature is 11°C found in January and maximum temperature is 32°C found during April, May, June, July, August and September. In Kharif-1 season, the maximum temperature varies between 30°C and 32°C and the minimum temperature varies from 17°C to 25°C. In Kharif-2 season, the maximum temperature varies from 31°C to 32°C and the minimum temperature varies from 23°C to 26°C. In Rabi season, the maximum temperature varies from 23°C to 28°C and the minimum temperature varies from 11°C to 17°C.

The average annual rainfall of this upazila is 2315 mm. The minimum rainfall occurs in December, which is 8 mm and maximum rainfall of 478 mm in July. The maximum rainfall is 453 mm and minimum rainfall is 26 mm in Kharif-1 season. In Kharif-2 season, the maximum rainfall is 478 mm and the minimum rainfall is 178 mm. The maximum and the minimum rainfall are 12 mm and 8 mm

respectively in Rabi season.The monthly climate scenario of GangacharaUpazila is presented in Figure 4b-(i).

Nachole Upazila: The average temperature of Nachole upazila is 26°C while the average minimum temperature is 20°C and the average maximum temperature is 31°C. The minimum temperature is 11°C found in January and maximum temperature is 36°C found during April. In Kharif-1 season, the maximum temperature varies between 33°C and 36°C and the minimum temperature varies from 18°C to 26°C. In Kharif-2 season, the maximum temperature varies from 32°C to 33°C and the minimum temperature varies from 23°C to 26°C. In Rabi season, the maximum temperature varies from 24°C to 29°C and the minimum temperature varies from 11°C to 17°C.

The average annual rainfall of this upazila is 1514 mm. The minimum rainfall occurs in December, which is 9 mm and maximum rainfall of 337 mm in July. The maximum rainfall is 251 mm and minimum rainfall is 26 mm in Kharif-1 season. In Kharif-2 season, the maximum rainfall is 337 mm and the minimum rainfall is 122 mm. The maximum and the minimum rainfall are 15 mm and 9 mm respectively in Rabi season. Figure 4b-(ii) depicts the monthly climate scenario of Nachole Upazila.

Nakla Upazila: The average temperature of Nakla upazila is 26°C while the average minimum temperature is 20°C and the average maximum temperature is 30°C. The minimum temperature is 12 °C found in January and maximum temperature 32°C found during April, May and June. In Kharif-1 season, the maximum temperature varies between 31°C and 32°C and the minimum temperature varies from 19°C to 26°C. In Kharif-2 season, the maximum temperature varies from 31°C to 32°C and the minimum temperature varies from 23°C to 26°C. In Rabi season, the maximum temperature varies from 24°C to 29°C and the minimum temperature varies from 12°C to 18°C.

The average annual rainfall of this upazila is 2307 mm. The minimum rainfall occurs in January, which is 7 mm and maximum rainfall of 460 mm in July. The maximum rainfall is 395 mm and minimum rainfall is 40 mm in Kharif-1 season. In Kharif-2 season, the maximum rainfall is 460 mm and the minimum rainfall is 207 mm. The maximum and the minimum rainfall are 18 mm and 7 mm respectively in Rabi season. Figure 4b-(iii) shows the monthly climate scenario of Nakla Upazila.

Jagannathpur Upazila: The average temperature of Jagannathpur upazila is 26°C while the average minimum temperature is 21°C and the average maximum temperature is 30°C. The minimum temperature is 13°C found in January and maximum temperature is 32°C found during July, August and September. In Kharif-1 season, the maximum temperature varies between 31°C and 31°C and the minimum temperature varies from 19°C to 25°C. In Kharif-2 season, the maximum temperature varies from 31°C to 32°C and the minimum temperature varies from 23°C to 25°C. In Rabi season, the maximum temperature varies from 25°C to 30°C and the minimum temperature varies from 13°C to 19°C.

The average annual rainfall of this upazila is 4054 mm. The minimum rainfall occurs in January, which is 6 mm and maximum rainfall of 776 mm in July. The maximum rainfall is 748 mm and minimum rainfall is 139 mm in Kharif-1 season. In Kharif-2 season, the maximum rainfall is 776 mm and the minimum rainfall is 203 mm. The maximum and the minimum rainfall are 35 mm and 6 mm respectively in Rabi season. Figure 4b-(iv) depicts the monthly climate scenario of Jagannathpur Upazila.

Noakhali Sadar Upazila: The average temperature of Noakhali Sadar upazila is 26°C while the average minimum temperature is 22°C and the average maximum temperature is 30°C. The minimum temperature is 14°C found in January and maximum temperature is 33°C found during April and May. In Kharif-1 season, the maximum temperature varies between 31°C and 33°C and the minimum temperature varies from 20°C to 26°C. In Kharif-2 season, the maximum temperature varies from 31°C to 31°C and the minimum temperature varies from 25°C to 26°C. In Rabi season, the maximum temperature varies from 25°C to 29°C and the minimum temperature varies from 14°C to 20°C.

The average annual rainfall of this upazila is 3130 mm. The minimum rainfall occurs in December, which is 6 mm and maximum rainfall of 748 mm occurs in July. The maximum rainfall is 562 mm and minimum rainfall is 72 mm in Kharif-1 season. In Kharif-2 season, the maximum rainfall is 748 mm and the minimum rainfall is 207 mm. The maximum and the minimum rainfall are 43 mm and 6 mm respectively in Rabi season. Figure 4b-(v) summarizes the monthly climate scenario of Noakhali Sadar Upazila.

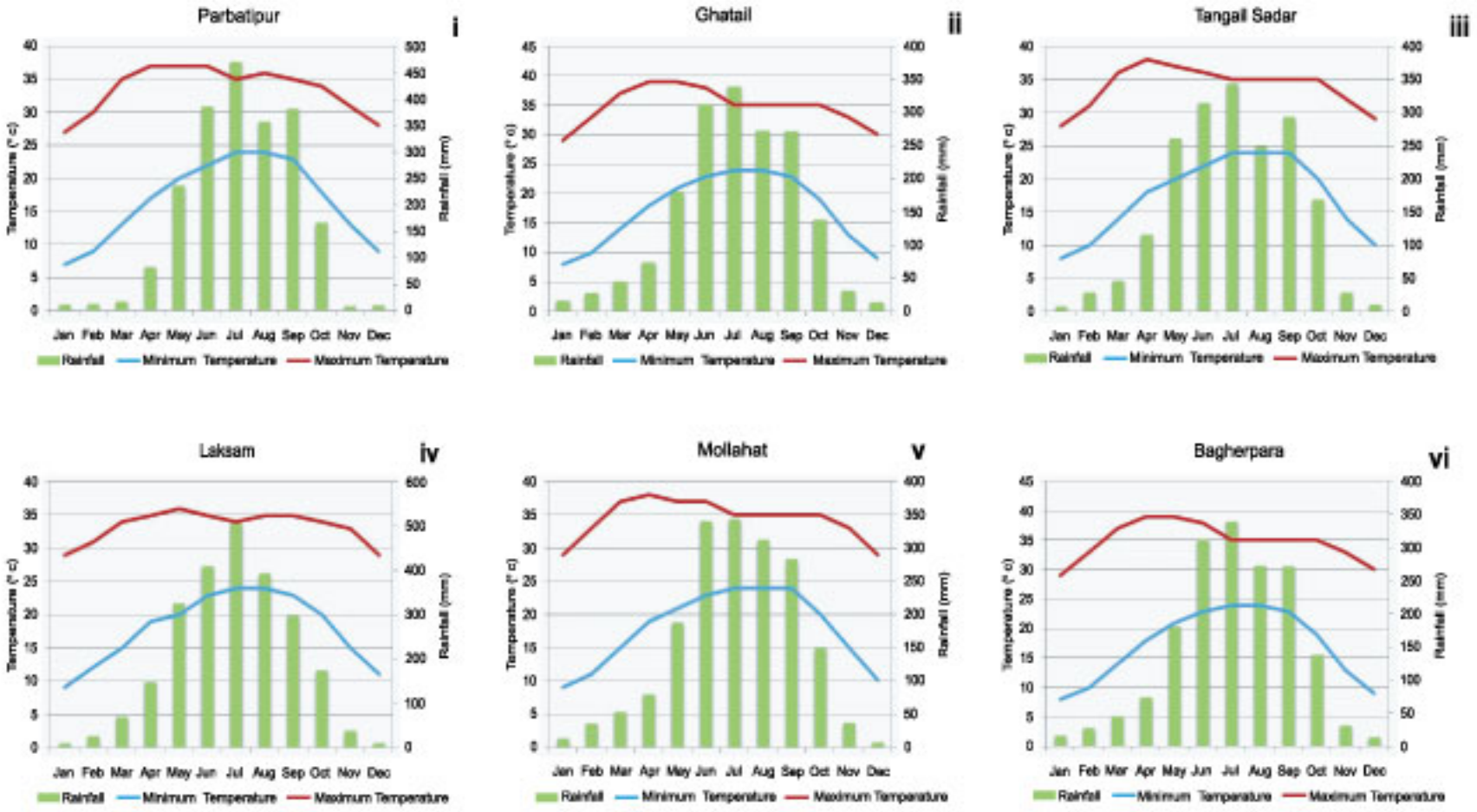


Figure 4(a). Monthly temperature and rainfall scenarios of selected upazilas (Source: BMD)

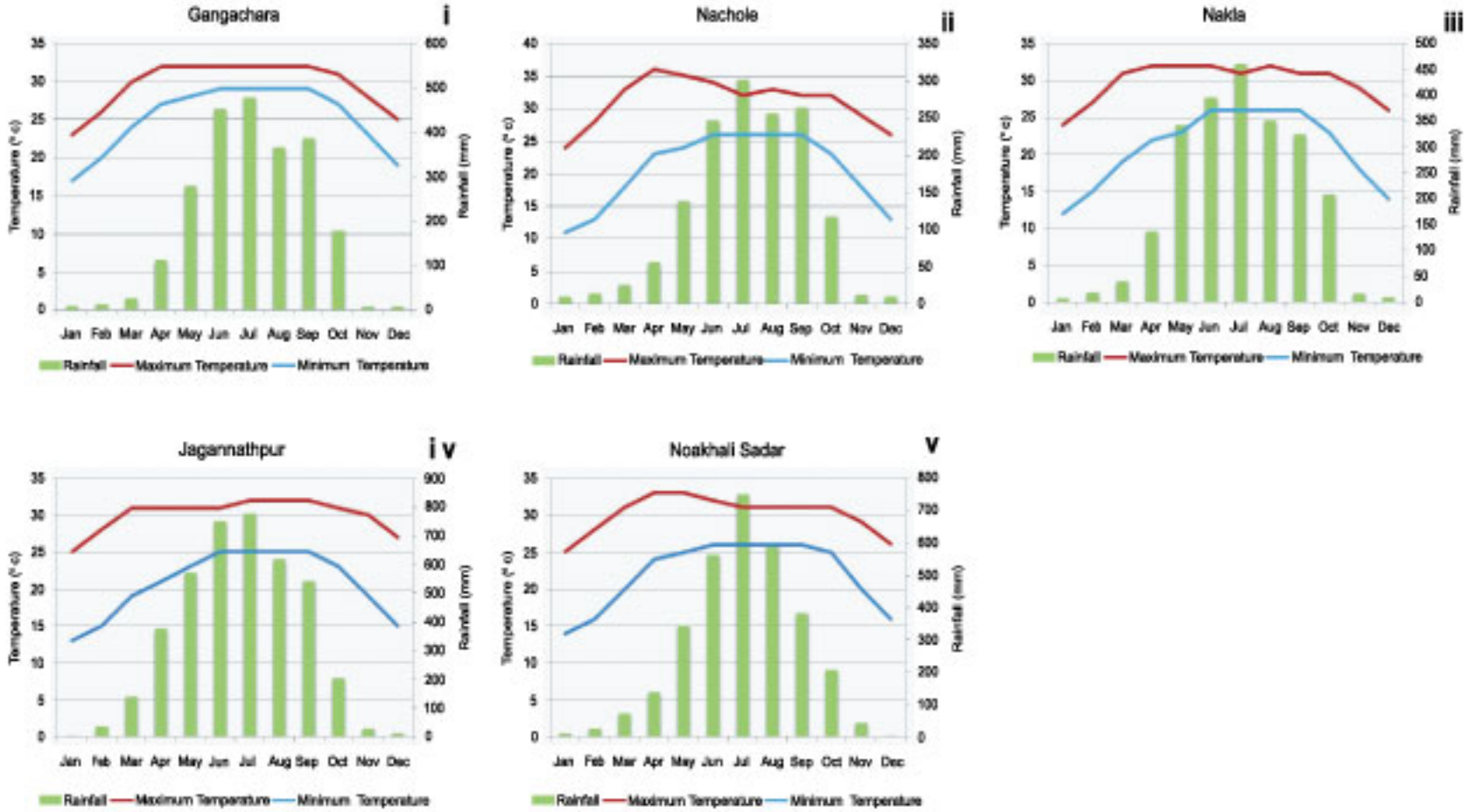


Figure 4(b). Monthly temperature and rainfall scenarios of selected upazilas (Source: BMD)

Database development

The database development was one of the important tasks carried out following the systematic steps (i) database design, (ii) approval from BARC, (iii) data capturing /digitization and processing, (iv) data quality checking and (v) database development and (vi) uploading the GIS database into the GIS based land use suitability tools.

The database-design process was carried out considering the data nature, format, source, quantity and security. Database consistency was checked following predefined methods. As part of the database design process, the entity-relationship diagram (E-R diagram) was developed. For this, the entities were identified through the data analysis based on the existing database of BARC (for instance, Land Resource Information System-LRIS). Then based on the characteristics of data, attributes were set to each entity. Finally, relationship was developed among the entities. The database design was done along with the field survey questionnaire and information required by the existing data structure of BARC. The database was designed in Geodatabase of ArcGIS and the procedure is presented in Figure 5. The data structures of the database is consistent with the existing database of BARC.

After designing of the database and collecting field and secondary data, data entry and processing work was done. The GIS data were captured and processed in ArcGIS and the attribute data especially those, collected from field were processed in MS Access. For entering field attribute and other secondary data, a data entry interface was designed in MS Access. After entering and processing, the processed database was imported into Geodatabase system of ArcGIS. The collected data were entered into the database under the guidance of a data entry supervisor and a programmer to ensure accuracy and consistencies. During entry, some parameters were automatically entered using developed lookup tables with interfaces such as locations (of upazilas, unions, mauzas, etc.), and zone name. All other parameters were then entered through the data entry interfaces developed under this study.

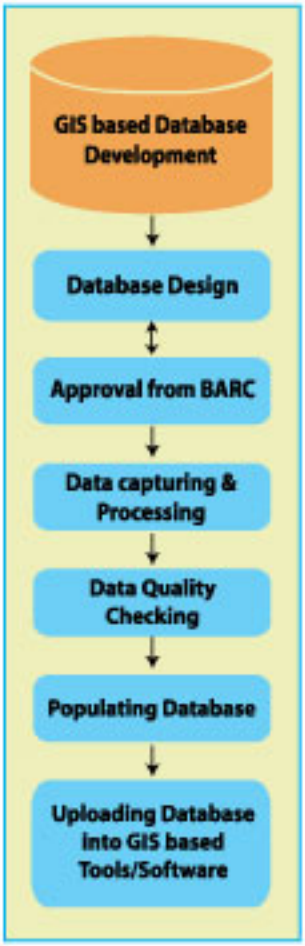


Figure 5. Development of Databases

Quality control of the data entry was done through randomly checking and graphical and visual interpretation. For data consistency, the locations of the farms, land type and other relevant information were checked with administrative boundaries (upazila, union, mauza, etc.) and BBS administrative names. Furthermore, all attribute data and spatial data were processed using ArcGIS software.

A comprehensive and well-organized database was developed considering the existing MIS and National level database.

The database development activities included (i) organization of field data, (ii) organization of secondary data, and (iii) integration of all type data into a database system and (iv) database development. The following major databases were developed:

Database on DEM (Digital Elevation model) and land type: Updated digital elevation database were prepared from the primary and/or secondary sources (Coastal map of Bangladesh, BWBD irrigation map data etc.) with high precision so that the existing land types can be further classified within a mapping unit boundary using GIS techniques.

Database on Meteorological parameter: Climatic data has been updated using latest information from BMD for the major climatic parameters and also from the rainfall stations of BWDB located in the study areas. The database also contains the water resources of the study areas including the surface and groundwater that were collected from BWDB and also from the field observations. Further NWRD and ICRD databases helped in developing the hydrological and meteorological database for the selected study upazila.

Database on soils and landforms: The landforms and major soil characteristics of the study areas were studied. It has been compared with the updated information provided by SRDI and further necessary updating has been made on it. The soil map of the Upazila Nirdeshika has been used for reviewing the physical and morphological characteristics of the soils of the selected areas.

Database on agriculture: Field survey has been carried out to collect information on land use distribution, cropping pattern, crop yields, and farm management practices. These primary databases of the study areas were helpful in updating the land suitability database of the study areas. Map has also been produced on present land use practices including cropping patterns using remote sensing technology.

Socioeconomic Database: One of the major objectives of the sub-project was to incorporate the socioeconomic factors with the physical factors of the land suitability database. Unless the socioeconomic condition of the farmers of the study areas is reflected in the land suitability assessment, farmers will not accept the crop suitability for their land. So a significant effort was made in developing this primary database from the field survey and using BBS census, community series and other relevant publications. Several interactive meetings were arranged between Soil/Agricultural Specialist and Socio-economist for identifying the socio-economic parameters important for supporting sustainable farming practices.

Preparation of crop and land suitability database: Land use and crop suitability database was developed considering the assessment method developed by the FAO/UNDP project on Land Resources Appraisal of Bangladesh for agricultural development, SRDI, and BARC. The database of soil, water and climatic parameters considered for crop suitability of the major crops were collected from BARC database. Present achieved yield rate of the major crops grown in selected upazilas were collected from Agricultural Research stations and DAE. Based on the outputs of land use/crop suitability assessment tools and existing database available at BARC/SRDI and other organization, the suitability database was prepared.

Updated Crop Suitability Database: The proposed crop/land suitability database mentioned in the earlier steps has been updated through field verifications and also utilized the research findings of the National Agricultural Research System (NARS) institutions. Further, ground truthing of the updated crop suitability database was done considering the environmental and other socioeconomic factors. The initial findings of the study in consultation with BARC and other NARS institutions was shared and consulted with the relevant professionals (e.g. Agricultural Expert and as well as other relevant experts) and stakeholder organizations.

Finally, after developing, all the databases were uploaded/integrated into the GIS based land use/crop suitability assessment tools/software Crop Suitability Assessment Model (CSAM).

Updating the land type maps

The land type updating was carried out through two sub-tasks are (i) updating of Digital Elevation Model (DEM) and (ii) updating Upazila Nirdeshika maps through delineating land types within different mapping units of the selected upazilas.

Preparation of updated Digital Elevation Model (DEM): The Digital Elevation Model (DEM) or the digital representation of ground surface topography or terrain is very useful for terrain analysis in a variety of sectors, especially in land, water and environment. The 300 meter resolution DEM of each upazila was updated and prepared new DEM by using the spot values extracted from BWDB irrigation maps and the coastal map (e.g. familiar with FINN map) of Bangladesh. The FINN maps are the high-resolution topographic maps at the 1:10,000 scales were produced from aerial photograph for coastal areas by FINNIDA.

The simplest interpolation method, Inverse Distance Weighted (IDW) was used to create the DEM with a spatial resolution of 100m×100m. This estimated surface values for each cell using the value and distance of nearby points. It was then used to classify different land types within a mapping unit boundary using GIS techniques. The spot height data and DEM of Tangail Sadar upazila is shown in Figure 6.

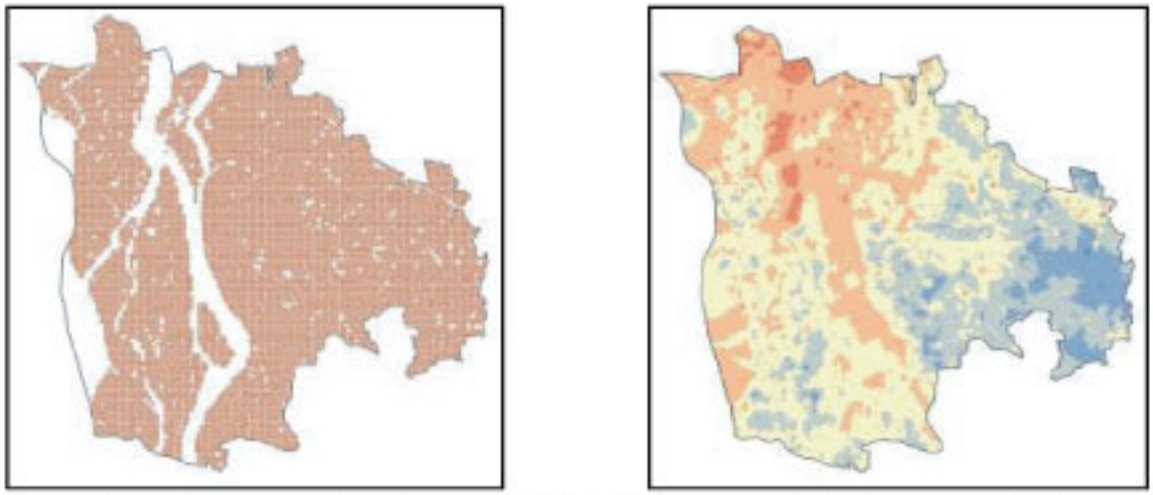


Figure 6. (a) Spot Height Map of Tangail Sadar Upazila and (b) Digital Elevation Model (DEM)

Update of land type map: The updated land type maps were prepared using the updated DEM, Upazila Nirdeshika soil unit map and applying conceptual calculation methods in GIS. It should be mentioned that the mapping unit polygons of the Upazila Nirdeshika consist of different soil boundaries and other classifications including rivers, water bodies/ponds, and homestead areas. The mapping unit boundary does not have any physical demarcation of land types. However, the database contains the percentage of area that falls under different land types for each mapping unit. In this study, different land types within the mapping units have been delineated based on the tabular data and with the help of updated DEM.

Preparation of updated land type map: In this study, the land type was classified with the help of DEM data at 100 meter × 100 meter grid. The following sub-steps were followed for land type updating:

(a) The mapping unit boundaries was overlaid with the DEM data using GIS application to extract the elevation for each cell boundary for each mapping unit;

(b) Then, the percentage of cumulative area according to elevation was produced for each mapping unit;

(c) Next, the percentage area of different land types of each mapping unit was used to get the divide line of elevation between two land types; and

(d) Finally, the mapping unit boundary was classified with new sub units to define the land types.

The landtype updating conceptual framework has been given in Figure 7.

After following steps (a-d), the land types were then classified following rule of area-elevation curve in GIS. The classification of land type using the area-elevation curve development procedure for each land type is shown in Figure 8.

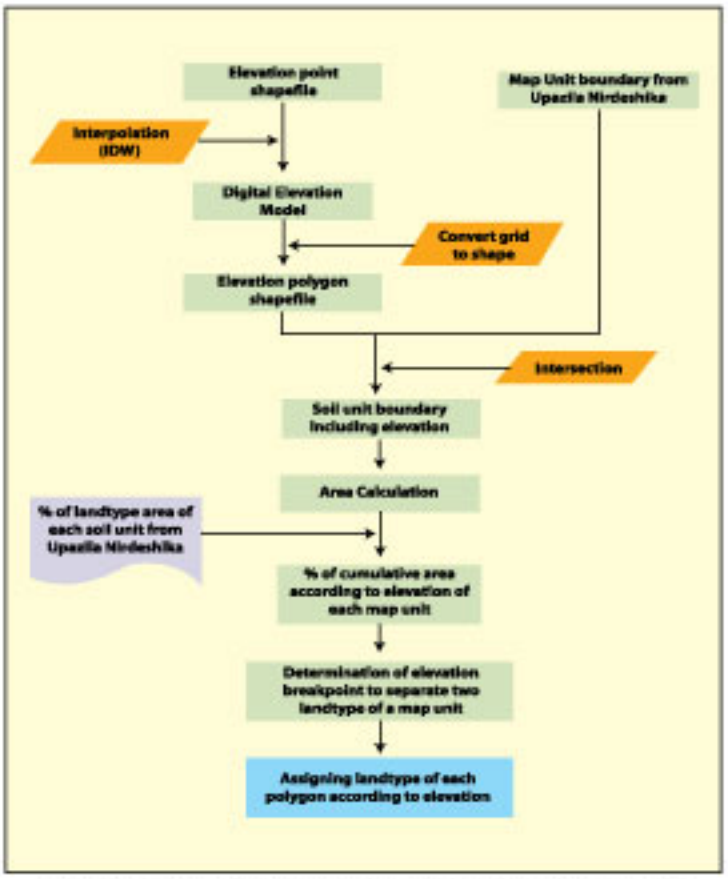


Figure 7. Conceptual process/framework of land type update

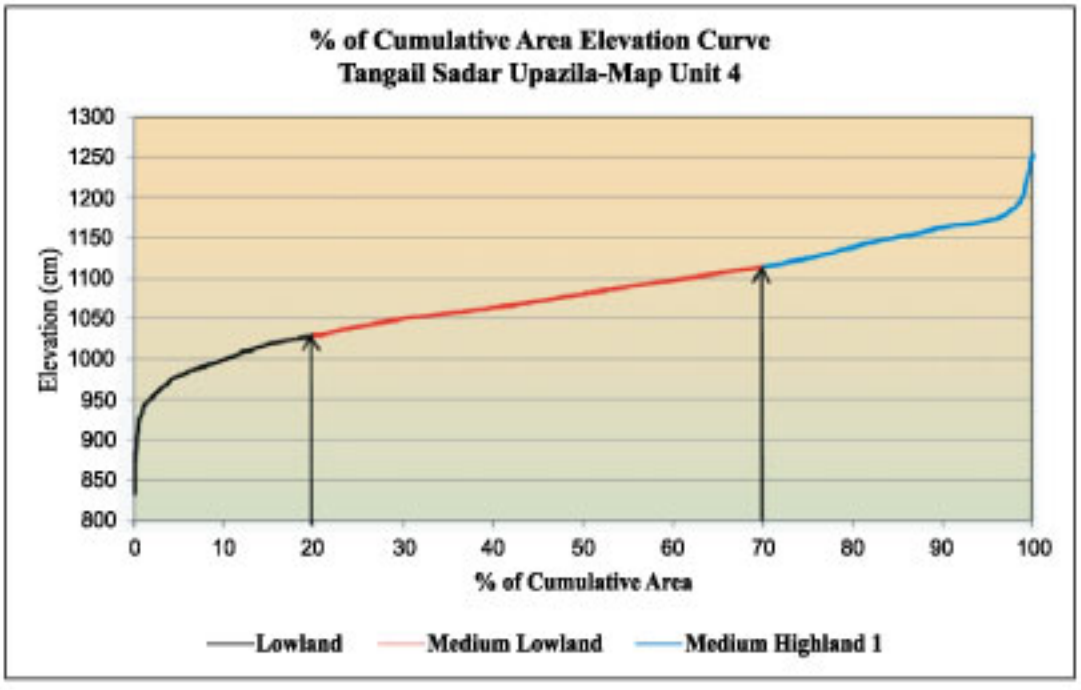


Figure 8. Classification of land type using the area-elevation curve development procedure

Baseline survey

Baseline survey was one of the prerequisites for assessing the land use and crop suitability of the study area. The baseline information was collected considering the soils, topographical, meteorological, agricultural and socio-economical aspects. Different techniques and methods were used in collecting the field based primary data for identifying the current institutional mechanism, policy strategies and indigenous techniques of land use/crop suitability assessment and their management plan. The major approaches and methods used and applied in the baseline survey were:

- Farmer's household level interview;
- Small group discussion and workshop at farmer's field;
- Community transects walk for resource mapping and marketing facility of agricultural product;
- Questionnaire survey;
- Collect secondary data on cropping pattern, land type etc. from local Upazila Agriculture Officer of the Department of Agricultural Extension (DAE).

The data and information collected under baseline survey are attributed below:

General information:	**Socio-economic information:**	**Financial information:**
• Household size • Area of cropped land • Available livestock • Off farm income • Farm income • Crops type and yield by season • Reason for production • Source of draught power	• Product price and demand • Access to market • Availability of market	• Access to banking facilities • Use of formal and informal credit
Information on technology used for production:	**Others important information relevant with production:**	**Information on infrastructural facilities:**
• Use of technology • Dependency on traditional irrigation	• Cost of production • Availability of seeds/fertilizers/irrigation water/electricity support/petroleum/pesticide • Cost of seeds/fertilizers/pesticide • Dependency on rain	• Condition of roads • Availability and use of production processing and storage facilities; and their distance from field • Transportation cost: house to field to market
Others information:		
• Illegal toll collection • Presence of middlemen		

Development of an appropriate research methodology is very vital for conducting any baseline survey. In this study, a particular method was used to follow different steps of the baseline survey. Figure 9 shows the adopted methodology for conducting the survey. The main objective of the survey was to find out the current status of agricultural and socio-economic conditions of the selected upazilas. The study team made field visits to all the upazilas with the following objectives:

a. Verification of land type updating methodology and validation of the land type boundary within a mapping unit boundary.

b. Questionnaire survey among the farmers in different spots of the study upazilas to collect base information related to agricultural and socio-economic conditions.

c. Integration of socio-economic information into the bio-physical database for crop suitability assessment.

Questionnaire development

Primary data collection through questionnaire survey for socio-economic research is common practice. This method was used to identify the constraints and opportunity of the study areas. Requirement of information, possible stakeholder and available resources were reviewed during the process of questionnaire development. This study used a well-structured questionnaire to gather field level information from the selected upazilas. The developed questionnaire and land type update methodology were finalized through a consultation meeting. Furthermore, pre-testing of the questionnaire and methodology of land type update was done in Tangail Sadar upazila. The questionnaire was then re-adjusted after the pre-testing. The questionnaire and land type update methodology were validated at field level (Figure 10).

Figure 9. Methodology of the baseline survey

Figure 10. Pilot survey for field checking of land type updating methodology and questionnaire validation

Land use mapping

Processing of satellite images was done for land use mapping. CEGIS has different types of satellite imageries and processing technology. These time series images were classified and prepared historical land use maps for facilitating the land use suitability mapping of selected upazilas. Further different types of baseline information were also extracted from the processed satellite images.

Data analysis and GIS mapping

CEGIS being the pioneer in developing the analytical thematic maps in Bangladesh, thus after database development and satellite image processing, detail data analysis and GIS mapping activity were carried out by CEGIS. Different types of GIS maps were generated using ArcGIS and developed GIS based tools.

Formation of field survey team and training

To conduct the baseline survey, a well experienced field team was formed. The selected members of the team were adequately qualified for conducting the baseline survey. They were experienced in similar field surveys as they worked in several projects of CEGIS. Before going for the survey, a day-long training on field data collection method and technique and overview about questionnaire was organized.

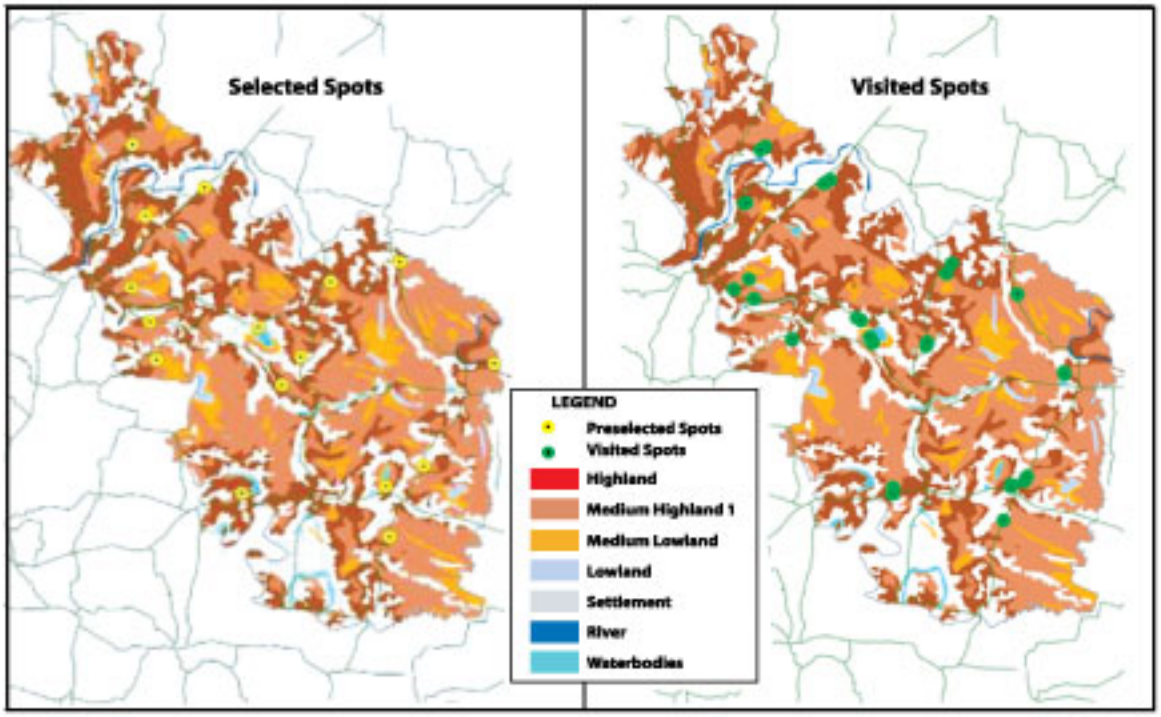


Figure 11.(a) Location map of Bagher Para showing spots selected and (b) spots visited by the survey team

Development of land use/crop suitability assessment framework

Earlier in methodology section it has been mentioned that the most important task of the study was to develop the land suitability assessment framework following the existing land suitability assessment process of BARC. The crop suitability assessment framework has been developed under this study following the multi-criteria analysis concept using different physical, climate and economic factors. The framework consists of different process such as ; (i) Land Type Updating, (ii) Edaphic Suitability Analysis, (iii) Agro-climate Suitability Analysis, (iv) Combined Suitability (Edaphic + Agro-climatic) Analysis, (v) Benefit cost ratio of individual crop, (vi) Major cropping pattern Analysis, (vii) Benefit cost ratio of major cropping patterns, (viii) Overall economic suitability of cropping pattern. The detail diagram of the land/crop suitability assessment procedure is presented in Figure 12.

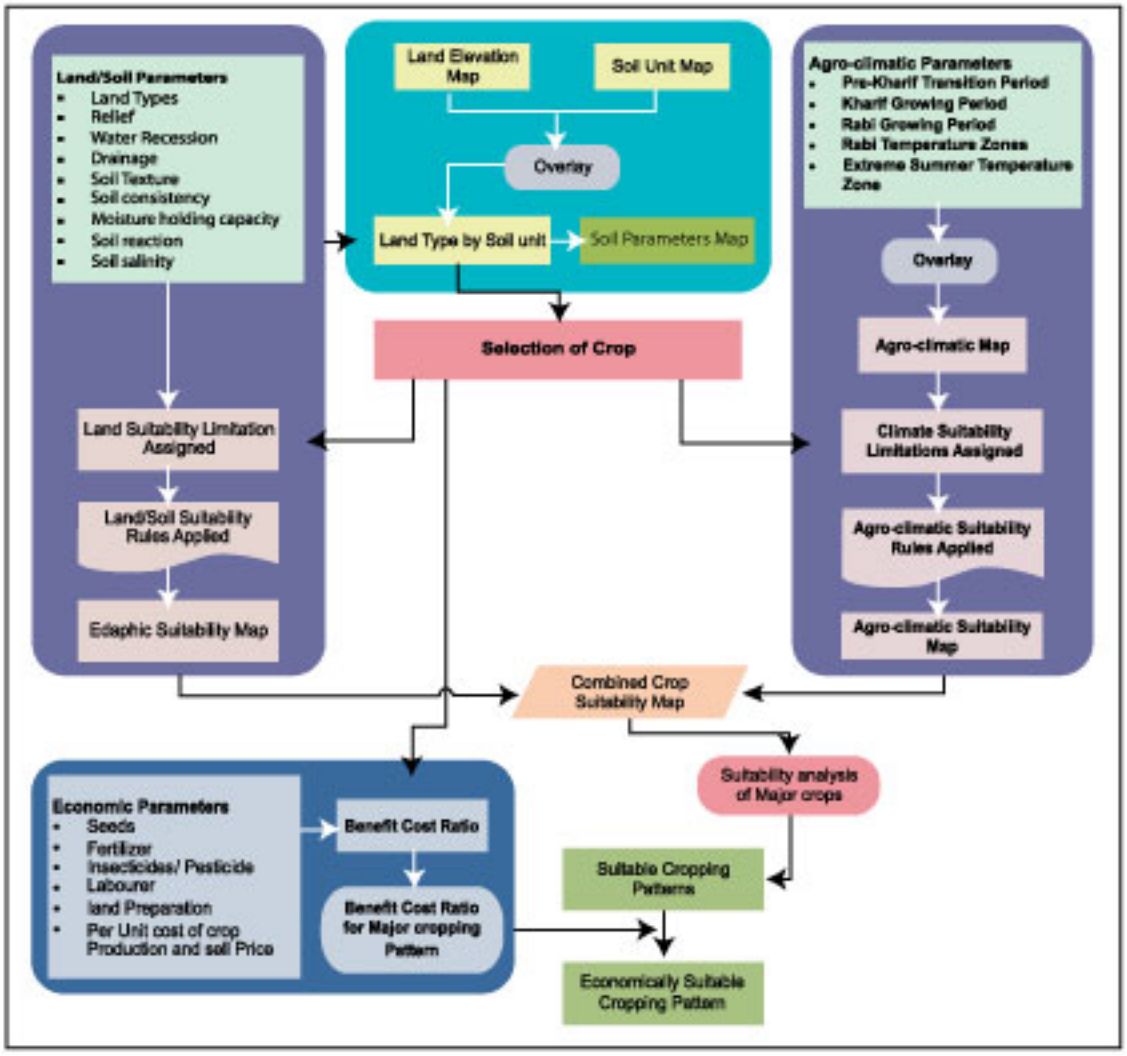


Figure 12. Detail diagram of land/crop suitability assessment framework

Development of crop/land use suitability assessment model (CSAM)

After developing the land use/crop suitability assessment framework, a user-friendly tool/model has been developed under ArcGIS environment which has been named as Crop Suitability Assessment Model (CSAM). All the databases developed are in MS Access interfaced with ArcGIS and the interface is designed with Visual Basic.

Land type updated with updated soil parameters and selection of crop

The updated land type map was prepared using the updated DEM, Upazila Nirdeshika soil unit map and applying conceptual calculation methods in GIS. After updating the land type, the updated soil parameters incorporated through overlaying the soil unit maps. Based on the updated soil parameters and land type, the specific crop can be selected from the list of crops for any specific upazilas.

Edaphic Suitability Analysis

Suitability of crops depends on different physical and chemical properties of land and soil. In determining the crop suitability nine major soil and land properties were considered. The major properties are Land type, Soil relief, Water recession, Drainage, Soil texture, Soil consistency, Available soil moisture, Soil reaction and Soil salinity. These parameters are classified according to the different levels of magnitude/intensity. Specific crop suitability was assessed by considering the degree of physical factors that limit the growth and potential yields of the crop. The physical suitability evaluation used the limiting factors method for assigning the suitability classes. Five degrees of limitation (Table 5) used in this study are given below and description of land factors are given in table 6.

Table 5. Degrees of limitation for assigning the suitability class

0	No limitation, representing the most favorable condition;
1	Slight limitation;
2	Moderate limitation;
3	Severe limitation;
4	Very severe limitation; the soil is unsuitable for the land use type or particular crop consideration at the specified level of management.

The degrees of limitation (with respect to crop requirements) of each individual land factors (Table 6) for the production of crops were assessed. Accordingly degrees of limitation were imposed to each land/soil factor classes (Table 7). This was done on a scale of 0-4 and the basis of expert judgment from the NARS scientists and other experts who have wide knowledge and field experience on cultivation of the crops.

A customized GIS based tool was developed for preparing land utilization table on the basis of combined limitation ratings composed of individual land factor constraints for a particular crop. Then the degree of limitations assigned under each land unit is counted and concatenated (as shown in Table 8 column 5). Afterwards taking all these factors into account, an overall suitability rating for each land phase was derived based on the combined limitation ratings using the set of rules as shown in Table 8. This was accomplished on the basis of Zijsvelt's soil-crop suitability model which was introduced in 1979, revised by Brammer in 1985 and further revised by Hussain et al, in 2005. To determine the position in a scale of five, suitability classes and relationship between land suitability rating and number and degree of limitations presented in Table 8.

Table 6. Land factor classes, codes and descriptions

Soil Parameter	Codes	Class Name	Land factor descriptions
Land Type	101	Highland	No inundation
	102	Medium Highland	0-90 cm
	103	Medium Lowland	90-180 cm
	104	Lowland	180-300 cm
	105	Very Lowland	>300 cm
Soil Relief	201	Level	
	202	Slightly Undulating	
	203	Mainly Undulating	
	204	Undulating	
	205	Sloppy	

Soil Parameter	Codes	Class Name	Land factor descriptions
Soil Texture	301	Sand	Sand (>70%), Silt (<30%), Clay (<15%)
	302	Sandy Loam	Sand (43-85%), Silt (<50%), Clay (<20%)
	303	Loam	Sand (<52%), Silt (>28%), Clay (<27%)
	304	Clay Loam	Sand (<80%), Silt (<73%), Clay (20-40%)
	305	Clay	Sand (<65%), Silt (<60%), Clay (>35%)
Soil Consistency	401	Loose (Moist)	if the soil is non-coherent (single-grain structure) i.e, Sand
	402	Friable (Moist)	if the soil crushes easily under gentle to moderate pressure. i.e, Sandy Loam/Loam
	403	Firm (Moist)	if the soil crushes under strong pressure, but this is difficult to do between the thumb and forefinger. i.e, Clay Loam/Clay
Available Soil Moisture	501	Low	Less than one month
	502	Medium	One to two months
	503	High	Two to three months
	504	Very High	More than three months
Soil Reaction	601	Extremely Acidic	pH: <4.5
	602	Strongly Acidic	pH: 4.5-5.5
	603	Moderately Acidic	pH: 5.6-6.5
	604	Neutral	pH: 6.6-7.3
	605	Moderately Alkaline	pH: 7.4-8.4
	606	Strongly Alkanine	pH: 8.5-9.0
	607	Extremely Alkaline	pH: >9.0
Soil Salinity	701	Non Saline	< 2 dS/m
	702	Very Slightly Saline	2-4 dS/m
	703	Slightly Saline	4-8 dS/m
	704	Moderately Saline	8-12 dS/m
	705	Strongly Saline	12-15 dS/m
	706	Extremely Saline	>15 dS/m
Water drainage	801	Well Drained	Water drained from soil instantly, but not so rapidly.
	802	Moderately Well Drained	Water drained from soil slowly. So, soil remains wet for a certain time
	803	Imperfectly Drained	Water drained from soil badly or slowly. This soil often remains wet in rainy season due to rainfall.
	804	Poorly Drained	The soil remains under water from 15 days to 7/8 months.
	805	Very Poorly Drained	The land remains submerged under water for more than 8 months and remains wet throughout the year.
Water Recession	901	Extremely Early	by Mid October
	902	Very Early	by Mid October
	903	Early	within Mid October to Mid November
	904	Normal	within Mid November to Mid December
	905	Late	within Mid December to Mid January
	906	Very Late	after Mid January

Table 7. Degree of limitations imposed for different land factors for different crops

Soil Parameter	Codes	Aus	Aman	Boro	Wheat	Maize	Potato	Lentil	Mungbean/ Blackgram	Gram	Mustard	Groundnut	Chili	Onion/ Garlic	Sugarcane	Jute
Land Type	101	0	0	2	1	0	1	0	1	0	2	2	2	2	0	0
	102	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0
	103	2	4	0	2	3	1	3	3	2	1	1	1	1	4	0
	104	4	4	0	4	4	3	4	4	3	4	4	4	3	4	2
	105	4	4	0	4	4	4	4	4	4	4	4	4	4	4	4
Soil Relief	201	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	202	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
	203	3	3	3	3	3	3	2	3	3	3	3	3	3	3	3
	204	3	3	3	2	2	3	3	4	2	2	2	2	2	2	2
	205	4	4	4	4	4	4	2	4	4	4	4	0	4	4	4
Soil Texture	301	4	4	4	4	4	4	4	4	4	4	4	0	4	4	4
	302	4	4	4	2	2	0	4	2	1	2	0	2	2	2	2
	303	0	0	0	0	0	0	2	0	0	0	0	0	0	0	0
	304	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	305	0	0	0	2	2	2	0	2	0	4	4	2	4	2	2
Soil Consistency	401	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4
	402	0	1	0	0	0	0	4	0	0	0	0	0	0	0	0
	403	0	0	0	1	1	1	0	1	0	1	1	1	1	1	1
Available Soil Moisture	501	0	0	0	0	0	0	1	4	4	2	4	0	4	0	3
	502	0	0	0	0	0	0	2	1	2	0	2	0	1	0	0
	503	0	0	0	0	0	0	4	0	0	1	0	0	0	0	0
	504	0	0	0	0	0	0	4	0	0	4	0	0	0	0	1
Soil Reaction	601	3	4	4	4	4	4	0	4	4	4	4	4	4	4	4
	602	1	2	2	2	2	2	4	2	2	2	2	2	2	2	2
	603	0	0	0	0	0	0	2	0	0	0	0	0	0	0	0
	604	0	0	0	0	0	0	2	0	0	0	0	0	0	0	0
	605	0	0	0	2	0	0	0	0	0	0	0	0	0	0	0
	606	2	2	2	4	2	2	0	2	2	2	2	2	2	2	2
	607	2	4	4	0	4	4	2	4	4	4	4	4	4	4	4
Soil Salinity	701	0	0	0	0	0	0	4	0	0	0	0	0	0	0	0
	702	1	1	2	0	2	1	0	1	3	1	1	0	1	1	2
	703	2	2	3	1	4	2	3	2	0	3	2	1	4	2	3
	704	3	2	3	2	4	4	4	4	0	4	3	2	4	3	3
	705	3	2	4	2	4	4	4	4	0	4	3	2	4	3	3
	706	4	3	4	3	4	4	4	4	0	4	4	4	4	4	4
Water drainage	801	4	3	4	0	0	0	4	1	1	0	0	0	0	0	0
	802	2	2	3	0	0	0	2	1	0	0	0	0	0	0	0
	803	0	0	0	0	0	0	2	2	0	1	0	1	0	2	0
	804	0	0	0	2	3	4	0	2	1	3	3	1	1	2	2
	805	0	0	0	4	4	4	1	4	4	4	4	4	4	4	4
Water Recession	901	0	0	0	0	0	0	4	0	0	0	0	0	0	0	0
	902	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	903	0	0	0	0	0	0	0	0	0	0	0	0	2	2	0
	904	0	0	0	0	0	2	0	4	0	2	2	2	2	4	2
	905	0	0	0	0	2	4	4	4	4	4	4	4	4	4	4
	906	4	4	0	4	4	4	4	4	4	4	4	4	4	4	4

Table 8. Relationship between land suitability rating and number and degree of limitations

Codes	Description	Percent MAT (Maximum Attainable Yield)	Number and degree of limitation	Concatcode 0-1-2-3-4	Edaphic Suitability
S1	**Very Suitable**	80 percent or more of MAT	All 0	9-0-0-0-0	1
			one 1, rest 0	8-1-0-0-0	1
			Two 1, rest 0	7-2-0-0-0	1
S2	**Suitable**	60 to 80 percent of MAT	Three 1, rest 0	6-3-0-0-0	2
			Four 1, rest 0	5-4-0-0-0	2
			One 2, rest 0	8-0-1-0-0	2
			One 1, two 1, rest 0	7-1-1-0-0	2
			One 2, two 1, rest 0	6-2-1-0-0	2
			Two 2, rest 0	7-0-2-0-0	2
S3	**Moderately Suitable**	40 to 60 percent of MAT	Five 1, rest 0	4-5-0-0-0	3
			Six 1, rest 0	3-6-0-0-0	3
			One 2, three 1, rest 0	5-3-1-0-0	3
			One 2, four 1, rest 0	4-4-1-0-0	3
			Two 2, one 1, rest 0	6-1-2-0-0	3
			Two 2, Two 1, rest 0	5-2-2-0-0	3
			Three 2, rest 0	6-0-3-0-0	3
			One 3, rest 0	8-0-0-1-0	3
			One 3, one 1, rest 0	7-1-0-1-0	3
			One 3, two 1, rest 0	6-2-0-1-0	3
			One 3, one 2, rest 0	7-0-1-1-0	3
			One 3, one 2, one 1, rest 0	6-1-1-1-0	3
S4	**Marginally Suitable**	20 to 40 percent of MAT	Seven 1, rest 0	2-7-0-0-0	4
			Eight 1, rest 0	1-8-0-0-0	4
			All 1	0-9-0-0-0	4
			One 2, five 1, rest 0	3-5-1-0-0	4
			One 2, six 1, rest 0	2-6-1-0-0	4
			Two 2, three 1, rest 0	4-3-2-0-0	4
			Two 2, four 1, rest 0	3-4-2-0-0	4
			Three 2, one 1, rest 0	5-1-3-0-0	4
			Three 2, two 1, rest 0	4-2-3-0-0	4
			Four 2, rest 0	5-0-4-0-0	4
			One 3, three 1, rest 0	5-3-0-1-0	4
			one 3, four 1, rest 0	4-4-0-1-0	4
			One 3, one 2, two 1, rest 0	5-2-1-1-0	4
			One 3, one 2, three 1, rest 0	4-3-1-1-0	4
			One 3, one 2, four 1, rest 0	3-4-1-1-0	4
			One 3, two 2, one 1, rest 0	5-1-2-1-0	4
			One 3, two 2, rest 0	6-0-2-1-0	4
			Two 3, rest 0	7-0-0-2-0	4
			Two 3, one 1, rest 0	6-1-0-2-0	4
S5	**Not Suitable**	Less than 20 percent of MAT	All other combinations		5

Climate Suitability Analysis

To carry out the task of agro-climate suitability, similar approach was followed considering length of kharif growing period, pre-kharif transition period, thermal zone and extreme temperature. The relationship between climate suitability rating and number and degree of limitations is given in Table 9.

Table 9. Relationship between climate suitability rating and number and degree of limitations

Code	Description	Number and degree of limitation	Concatcode	Climatic Suitability
VS	**Very Suitable**	All 0	4-0-0-0-0	1
		One 1, rest 0	3-1-0-0-0	1
S	**Suitable**	Three 1, one 2	0-3-1-0-0	2
		All 2	0-4-0-0-0	2
		Four 1, three 1, one 1, rest 0	1-1-0-1-1	2
		Four 1, two 1, one 1, rest 0	1-1-1-0-1	2
		Two 1, one 1, rest 0	2-1-1-0-0	2
		One 2, rest 0	2-2-0-0-0	2
		Three 1, rest 0	3-0-0-1-0	2
		Two 1, rest 0	3-0-1-0-0	2
MS	**Moderately Suitable**	Four 2, two 2	0-0-2-0-2	3
		Three 2, two 2	0-0-2-2-0	3
		Four 1, three 1, one 2	0-2-0-1-1	3
		Three 2, one 2	0-2-0-2-0	3
		Four 1, two 1, one 2	0-2-1-0-1	3
		Two 2, one 2	0-2-2-0-0	3
		Four 1, one 3	0-3-0-0-1	3
		Three 1, one 3	0-3-0-1-0	3
		Three 3, rest 0	1-0-0-3-0	3
		Four 1, three 1, two 1, rest 0	1-0-1-1-1	3
		Two 3, rest 0	1-0-3-0-0	3
		Three 1, two 1, one 1, rest 0	1-1-1-1-0	3
		Four 1, one 2, rest 0	1-2-0-0-1	3
		Three 1, one 2, rest 0	1-2-0-1-0	3
		Two 1, one 2, rest 0	1-2-1-0-0	3
		One 3, rest 0	1-3-0-0-0	3
		Four 1, three 1, rest 0	2-0-0-1-1	3
		Three 2, rest 0	2-0-0-2-0	3
		Three 1, two 1, rest 0	2-0-1-1-0	3
		Two 2, rest 0	2-0-2-0-0	3
		Four 1, one 1, rest 0	2-1-0-0-1	3
		Three 1, one 1, rest 0	2-1-0-1-0	3
		Four 1, rest 0	3-0-0-0-1	3
LS	**Marginally Suitable**	Four 2, three 2	0-0-0-2-2	4
		Four 1, three 3	0-0-0-3-1	4
		Three 3, two 1	0-0-1-3-0	4
		Four 1, two 3	0-0-3-0-1	4
		Three 1, two 3	0-0-3-1-0	4
		Four 3, one 1	0-1-0-0-3	4
		Three 3, one 1	0-1-0-3-0	4
		Four 2, one 2	0-2-0-0-2	4
		Four 3, rest 0	1-0-0-0-3	4
		Four 2, rest 0	2-0-0-0-2	4
NS	**Not Suitable**	All other combinations		5

VS=Very Suitable, S=Suitable, MS=Moderately Suitable, LS=Marginally Suitable, NS=Not Suitable

Combined Suitability Analysis

In the final stage of land suitability assessment, the agro-edaphic and agro-climatic suitability maps were overlaid to get the overall land suitability maps of different crops. The rules for combining these maps to classify and get land suitability maps has been presented in Table 10.

Table 10. Relationship between agro-climatic, agro-edaphic and land suitability classification

Agro-climatic suitability rating	Agro-edaphic suitability rating	Land suitability rating
VS	S1	VS
	S2	S
	S3	MS
	S4	LS
	N	NS
S	S1	S
	S2	MS
	S3	LS
	S4	LS
	N	NS
MS	S1	MS
	S2	LS
	S3	LS
	S4	NS
	N	NS
LS	S1	LS
	S2	LS
	S3	NS
	S4	NS
	N	NS
NS	S1	NS
	S2	NS
	S3	NS
	S4	NS
	N	NS

VS=Very Suitable, S=Suitable, MS=Moderately Suitable, LS=Marginally Suitable, NS=Not Suitable

Benefit cost ratio

There are many different crops in the study areas. Major crops are considered as per scope of the study for estimation of economic return. Economic return is directly interrelated to production of crops, cost of production and market price of crops. There are some sub-component of cost of crop production such as seeds, fertilizer, insecticides/pesticide, labour, land preparation, etc. Net economic return has been calculated by considering total production, per unit cost of crop production and sell price of the particular crop. It was also calculated for food security and financial benefit. All data have been used from Department of Agricultural Extension (DAE) and Bangladesh Bureau of Statistics (BBS).

Cropping pattern Analysis

Cropping pattern is the annual sequence and spatial arrangement of crops and fallow grown on a given land. For cropping pattern analysis fourteen important crops for three cropping seasons were selected (Figure 13). Firstly, the agro-edaphic and agro-climatic suitability of those 14 crops were evaluated. Then combined suitability were determined for each crop. Secondly, all possible cropping patterns with suitability rating for all crops were assessed by considering three cropping seasons.

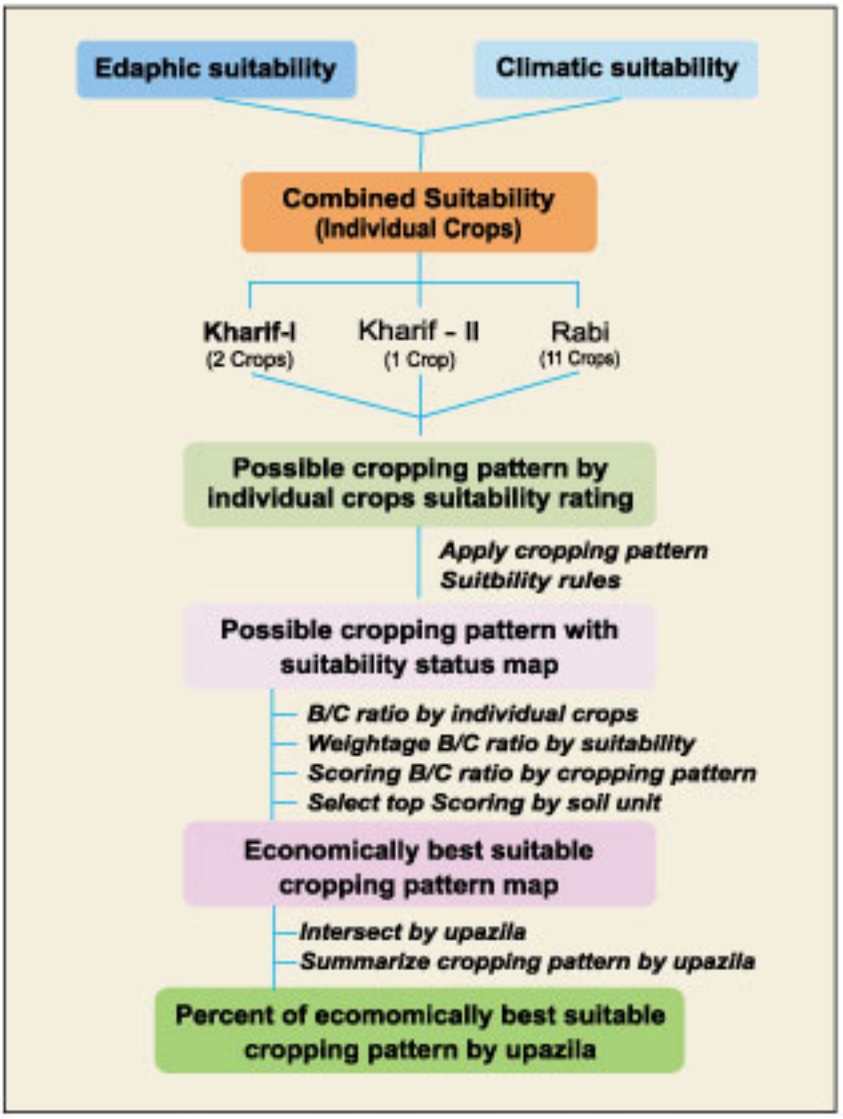


Figure 13. Cropping pattern suitability analysis

A cropping pattern database is created within each of the updated soil units and for the entire upazila. The rules for cropping pattern suitability assessment are presented in Table 11.

Table 11. Relation between cropping pattern and degree of limitations

Cropping pattern			Degree of limitations				Cropping Pattern Suitability
Kharif-I	Kharif-II	Rabi	Kharif-I	Kharif-II	Rabi	Total	
VS	VS	VS	0	0	0	0	VS
VS	VS	S	0	0	1	1	VS
VS	S	VS	0	1	0	1	VS
S	VS	VS	1	0	0	1	VS
VS	S	S	0	1	1	2	VS
S	VS	S	1	0	1	2	VS
S	S	VS	1	1	0	2	VS
VS	VS	MS	0	0	2	2	VS
VS	MS	VS	0	2	0	2	VS
MS	VS	VS	2	0	0	2	VS
S	S	S	1	1	1	3	S
VS	VS	LS	0	0	3	3	S
VS	LS	VS	0	3	0	3	S
LS	VS	VS	3	0	0	3	S
VS	S	MS	0	1	2	3	S
VS	MS	S	0	2	1	3	S
S	VS	MS	1	0	2	3	S
S	MS	VS	1	2	0	3	S
MS	VS	S	2	0	1	3	S
MS	S	VS	2	1	0	3	S
VS	MS	MS	0	2	2	4	S
MS	VS	MS	2	0	2	4	S
MS	MS	VS	2	2	0	4	S
VS	VS	NS	0	0	4	4	S
VS	NS	VS	0	4	0	4	S
NS	VS	VS	4	0	0	4	S
S	S	MS	1	1	2	4	S
S	MS	S	1	2	1	4	S
MS	S	S	2	1	1	4	S
VS	S	LS	0	1	3	4	S
VS	LS	S	0	3	1	4	S
S	VS	LS	1	0	3	4	S
S	LS	VS	1	3	0	4	S
LS	VS	S	3	0	1	4	S
LS	S	VS	3	1	0	4	S
S	MS	MS	1	2	2	5	S
MS	S	MS	2	1	2	5	S
MS	MS	S	2	2	1	5	S
S	S	LS	1	1	3	5	S
S	LS	S	1	3	1	5	S

Cropping pattern			Degree of limitations				Cropping Pattern Suitability
Kharif-I	Kharif-II	Rabi	Kharif-I	Kharif-II	Rabi	Total	
LS	S	S	3	1	1	5	S
VS	S	NS	0	1	4	5	S
VS	MS	LS	0	2	3	5	S
VS	LS	MS	0	3	2	5	S
VS	NS	S	0	4	1	5	S
S	VS	NS	1	0	4	5	S
S	NS	VS	1	4	0	5	S
MS	VS	LS	2	0	3	5	S
MS	LS	VS	2	3	0	5	S
LS	VS	MS	3	0	2	5	S
LS	MS	VS	3	2	0	5	S
NS	VS	S	4	0	1	5	S
NS	S	VS	4	1	0	5	S
MS	MS	MS	2	2	2	6	MS
VS	LS	LS	0	3	3	6	MS
LS	VS	LS	3	0	3	6	MS
LS	LS	VS	3	3	0	6	MS
S	S	NS	1	1	4	6	MS
S	NS	S	1	4	1	6	MS
NS	S	S	4	1	1	6	MS
VS	MS	NS	0	2	4	6	MS
VS	NS	MS	0	4	2	6	MS
S	MS	LS	1	2	3	6	MS
S	LS	MS	1	3	2	6	MS
MS	VS	NS	2	0	4	6	MS
MS	S	LS	2	1	3	6	MS
MS	LS	S	2	3	1	6	MS
MS	NS	VS	2	4	0	6	MS
LS	S	MS	3	1	2	6	MS
LS	MS	S	3	2	1	6	MS
NS	VS	MS	4	0	2	6	MS
NS	MS	VS	4	2	0	6	MS
S	LS	LS	1	3	3	7	MS
LS	S	LS	3	1	3	7	MS
LS	LS	S	3	3	1	7	MS
MS	MS	LS	2	2	3	7	MS
MS	LS	MS	2	3	2	7	MS
LS	MS	MS	3	2	2	7	MS
VS	LS	NS	0	3	4	7	MS
VS	NS	LS	0	4	3	7	MS
S	MS	NS	1	2	4	7	MS
S	NS	MS	1	4	2	7	MS

Cropping pattern			Degree of limitations				Cropping Pattern Suitability
Kharif-I	Kharif-II	Rabi	Kharif-I	Kharif-II	Rabi	Total	
MS	S	NS	2	1	4	7	MS
MS	NS	S	2	4	1	7	MS
LS	VS	NS	3	0	4	7	MS
LS	NS	VS	3	4	0	7	MS
NS	VS	LS	4	0	3	7	MS
NS	S	MS	4	1	2	7	MS
NS	MS	S	4	2	1	7	MS
NS	LS	VS	4	3	0	7	MS
VS	NS	NS	0	4	4	8	MS
NS	VS	NS	4	0	4	8	MS
NS	NS	VS	4	4	0	8	MS
MS	LS	LS	2	3	3	8	MS
LS	MS	LS	3	2	3	8	MS
LS	LS	MS	3	3	2	8	MS
MS	MS	NS	2	2	4	8	MS
MS	NS	MS	2	4	2	8	MS
NS	MS	MS	4	2	2	8	MS
S	LS	NS	1	3	4	8	MS
S	NS	LS	1	4	3	8	MS
LS	S	NS	3	1	4	8	MS
LS	NS	S	3	4	1	8	MS
NS	S	LS	4	1	3	8	MS
NS	LS	S	4	3	1	8	MS
LS	LS	LS	3	3	3	9	LS
S	NS	NS	1	4	4	9	LS
NS	S	NS	4	1	4	9	LS
NS	NS	S	4	4	1	9	LS
MS	LS	NS	2	3	4	9	LS
MS	NS	LS	2	4	3	9	LS
LS	MS	NS	3	2	4	9	LS
LS	NS	MS	3	4	2	9	LS
NS	MS	LS	4	2	3	9	LS
NS	LS	MS	4	3	2	9	LS
MS	NS	NS	2	4	4	10	LS
NS	MS	NS	4	2	4	10	LS
NS	NS	MS	4	4	2	10	LS
LS	LS	NS	3	3	4	10	LS
LS	NS	LS	3	4	3	10	LS
NS	LS	LS	4	3	3	10	LS
LS	NS	NS	3	4	4	11	LS
NS	LS	NS	4	3	4	11	LS
NS	NS	LS	4	4	3	11	LS
NS	NS	NS	4	4	4	12	NS

Economically suitable cropping pattern

Economically best suitable cropping pattern was developed by using benefit cost (B/C) ratio and combined suitability rating of individual crop. The benefit cost ratio was estimated considering maximum attainable yield. Then the benefit cost ratio for individual crops was multiplied by 1, 0.8, 0.6, 0.4 and 0.2 for suitability rating of VS, S, MS, LS and NS respectively. The sum of benefit cost ratios for a year was calculated following descending order by updated soil unit. The top score obtaining pattern was considered as the economically best suitable cropping pattern. Similarly, the second and third top score obtaining patterns were the second and third economically best suitable cropping patterns.

Field validation of outputs of GIS based suitability assessment tools

After generating the outputs (maps and table, graphs) from GIS based crop suitability assessment tools (CSAM), validation of the maps were carried out in the fields. Field level consultation meeting and focus group discussion were organized to validate the maps including physical visit at the farmer's plots.

9. Results and discussions

This special study was not a typical agricultural research project. It was basically a Baseline survey and a decision support system (software) development assignment. Therefore, development of various algorithms, rules for different processes are the primary results and the outputs are the secondary results. The baseline survey was primarily done to understand and document various farming, household, socio-economic aspects of the surveyed upazilas and eventually use the gathered knowledge in developing the model.

Baseline survey

Baseline survey was carried out in all the study areas e.g. in Parbotipur upazila of Dinajpur district, Tangail Sadar upazila and Ghatail upazila of Tangail district, Laksham upazila of Comilla district, and Mollahat and Bagher Para Upazila of Bagerhat and Jessore district respectively. The additional five upazilas included in the study namely; Gangachara Upazila of Rangpur district, Nachole Upazila of Nawabganj districts, Nakla Upazila of Sherpur district, Jagannathpur Upazila of Sunamganj district and Noakhali Sadar upazila of Noakhali district were also covered in the survey.

The Centre for Environmental and Geographic Information Services (CEGIS) mobilized the field team to collect field information from December 2013 and continue up to February 2013 (first slot) and again during April 2014 to May 2014 (second slot). The field survey team surveyed all the selected locations of the study areas. They visited all survey locations, validated the updated land type maps and completed a questionnaire survey by interviewing the farmers. Though it was difficult to access in all locations yet the field survey teams successfully completed their tasks in the due time. During the field surveys, the field teams had some specialized tasks like updated land type validation, focus group discussion and questionnaire survey. They also collected agricultural data from the respective Upazila Agriculture Officer of the Department of Agricultural Extension (DAE) of the selected upazilas. A separate monitoring team of senior officials from CEGIS, BARC and SRDI visited various fields to monitor the baseline survey and validation of land type update (Figure 14).

Figure 14. Location identification using GPS and questionnaire Survey for data collection

Questionnaire Survey

The selected field team collected data and information from farmers through direct interviews. Major information on the agricultural features i.e. cropping pattern, crop production, problems and satisfaction of the farmers on the current cropping pattern etc. was collected through the survey (Figure 15).

Figure 15. Questionnaire survey in the field

For this study, socio-economic data and information were also collected from the farmers through direct interview by the field survey team. The main information collected were socio-economic characteristics i.e. market for agricultural products, financial activities, labor input for crop production, technology input for crop production, other input for crop production, infrastructure and others.

Primary and also secondary data on the current cropping pattern, agricultural production demand, price, existing facilities of an area for crop processing, storage and transportation, and socio economic parameters such as use of formal or informal credit, illegal toll collection etc. were collected through questionnaire survey and literature review. A tool/questionnaire was developed to conduct the baseline survey in the selected study upazilas. Prior to the collection of primary data from the field, satellite images of the study areas were analyzed to acquire information on present land use practices. Baseline survey helped in the development of the database of the study areas. This primary information was used in updating the land type and land use database of the study areas.

Using the land type updating procedure developed under this study, land types of all the selected upazilas were updated and delineated on maps. As an example, the existing and updated land types of Tangail Sadar upazila is shown in Figure 16.

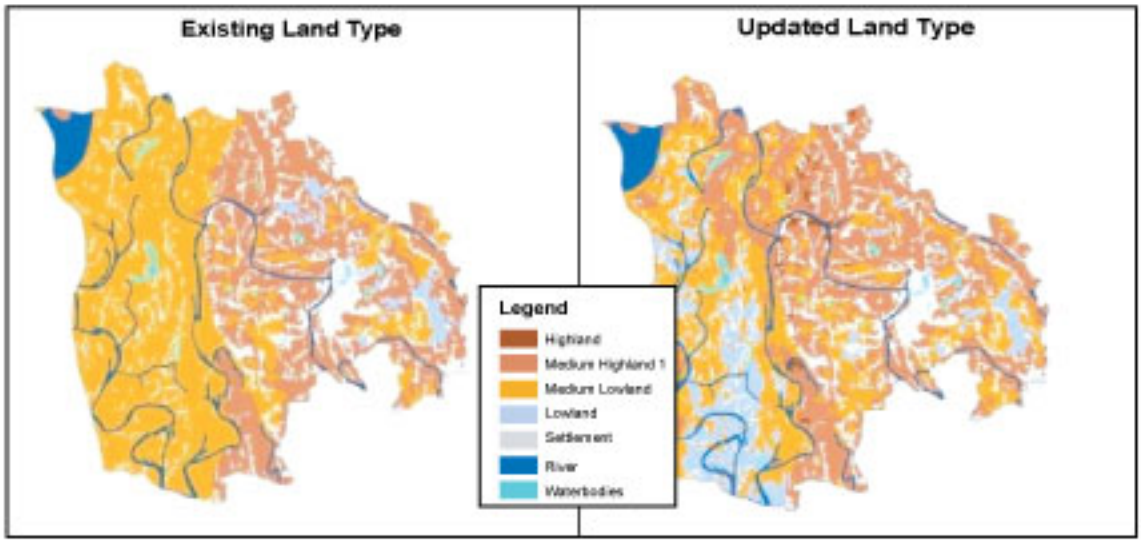


Figure16. Maps showing existing and updated land types in the Tangail Sadar upazila

Field validation of the updated land type maps

After generating the updated land type, field validation was carried out during baseline survey by comparing the land types on the maps with those in the field by locating the coordinates with GPS. The accuracy of the land type is more than 70%. After preparation of updated land type maps for the selected upazilas, those were validated in the field during baselines surveys.

Analysis of baseline survey data

Land Mapping Unit (LMU) is an area of land demarcated on a map with specified land characteristics and/or qualities (FAO, 1976). Map Unit is defined and mapped by the Soil Resource Development Institute (SRDI) where it has been demarcated based on physiographic and soil characteristic of land and possibility of land development. From Table 12 it is observed that Parbatipur upazila under Dinajpur district has the highest number mapping units which is 20 and Laksam upazila under Comilla district has the lowest number of mapping units which is eight.

Table 12. Number of map units in each upazila

District	Upazila	Number of Agricultural Map Unit	Number of Map Units
Dinajpur	Parbatipur	18	20
Tangail	Ghatail	15	18
Tangail	Tangail Sadar	8	11
Comilla	Laksam	4	8
Bagerhat	Mollahat	14	16
Jessore	Bagher Para	8	11
Noakhali	Noakhali Sadar	10	14
Sunamganj	Jagannathpur	6	10
Sherpur	Nakla	9	12
Nababganj	Nachole	11	15
Rangpur	Gangachara	10	13

Landuse

The landuse patterns of the study areas varied from place to place. According to the Upazila Nirdeshika of the selected upazilas of the first slot, in general, around 70 to 80% of land in the study areas is used for agriculture. However, in Ghatail and Parbatipur upazilas, more than 90% of land is used for agricultural purposes. On the other hand, in these two upazilas only 5% of land is used as settlement. In Bagher Para upazila around 30% of land is used as settlement while in the other three upazilas 15 to 20% of land is occupied by settlement. The remaining portions of the total land area are waterbodies e.g., rivers, ponds, haors, beels, etc. In Laksam upazila 0.007% of land is covered by *charland*.

In contrast, the RS PAN, 03 & Landsat 5 TM, (2010) information show that around 60 to 70% of land in the study areas is used for agricultural purposes. However, in Ghatail around 50% land is used for agriculture. In Bagher Para, Ghatail and Laksam upazila more than 30% of land is used as settlement, but it is around 15 to 20% in Mollahat, Parbatipur and Tangail Sadar upazila. Around 10% of area in Ghatail upazila and 1.42% land in Parbatipur upazila is covered by forest. Consequently, more than 10% of land in Mollahat and around 5% of land in Tangail Sadar is covered by others types like weeds or sands. The remaining portions of the total land area are occupied by railways, roads, and water bodies e.g., rivers, ponds, haors, beels, etc.

When the landuse information of Upazila Nirdeshika of the study areas is compared with satellite imagery, it is found that the area of agricultural land has reduced in all the six upazilas within the

range of 2 to 10%. But in Ghatail upazila substantial amount of agricultural land has been reduced which is about 40%. The main causes of such reduction are; around 10% area is covered by forest. In addition, the area of settlement with homestead garden found from the satellite images, increased by seven times than the Upazila Nirdeshika, which is around 30%. To find out the cause of such an increase of the settlement area, the image acquired from the Google earth was analyzed (Figure 18). It is found that with the increase of settlement area, people used the surrounding highland area as homestead garden. As a certain portion of Ghatail is highland, and the people living in this area used the highland for homestead garden, the total area of settlement has increased remarkably. Consequently, the extent of agricultural land has decreased. In general, in all the six upazilas, the coverage of the settlement with homestead garden extracted from the satellite images is found to increase by 5 to 10% compared to the Upazila Nirdeshika. Besides, a certain portion of the total area is covered by railways and roads, which is found from the satellite images but is not been considered in the Upazila Nirdeshika, maps. Figure 18 show the satellite image (a) and landuse map (b) of Ghatail upazila. The satellite images and landuse maps of other upazilas are presented in the Appendix Figures 1-9.

Figure 17. Image of Settlement in Ghatail Upazila acquired from Google earth

The landuse patterns of the study areas vary from place to place. According to the Upazila Nirdeshika of the selected upazilas, in general, around 70 to 80% of land in the study areas is used for agriculture. However, in Nachole and Nakla upazilas, more than 90% of land is used for agricultural purposes. On the other hand, in these two upazilas only 4% of land is used as settlement. In Jagannathpur Upazila around 8% of land is used as settlement while in the other three upazilas 5 to 6% of land is occupied by settlement. The remaining portions of the total land area are waterbodies e.g., rivers, ponds, haors, beels, etc. In Noakhali Sadar upazila 8% of land is covered by *clay swamp and 7% is forest*.

On the other hand, the Landsat 8 (2013) & Landsat TM, (2007) information show that around 50 to 80% of land in the study areas is used for agricultural purposes. However, in Noakhali Sadar around 50% land is used for agriculture. In Gangachara, Nakla and Noakhali Sadar upazila more than 30% of land is used as settlement, but it is around 15 to 20% in Nachole and Jagannathpur Upazila. Around 1.5% of area in Noakhali Sadar upazila is covered by forest. Consequently, more than 9% of land in Gangachara is covered by other types like weeds or sands. The remaining portions of the total land area are covered by railways, roads, and water bodies e.g., rivers, ponds, haors, beels, etc.

When the landuse information of the Upazila Nirdeshika of the study areas is compared with satellite imagery, it is found that the area of agricultural land has been reduced in all the five upazilas within the range of 10 to 20%. But in Gangachara and Nakla upazila substantial amount of agricultural land has been reduced which is about 29% and 27% respectively. The main causes of

such reduction are; around 10% area is covered by sand or weed. In addition, the area of settlement with homestead garden found from the satellite images to increase by seven times than the Upazila Nirdeshika which is around 20%. To find out the cause of such an increase of the settlement area, the image acquired from the Google earth was also analyzed. It is found that with the increase of settlement area, people used the surrounding highland area as homestead garden. Consequently, the extent of agricultural land has decreased. In general, in all the five Upazilas, the coverage of the settlement with homestead garden extracted from the satellite images is found to increase by 10 to 30% compared to the Upazila Nirdeshika data. Besides, a certain portion of the total area is covered by railways and roads, which is found from the satellite images but is not been considered in the Upazila Nirdeshika maps. Figure 19 shows the satellite image (a) and landuse map (b) of Gangachara upazila.

The comparison of landuse pattern of the selected study areas (percentage) between the satellite images and Upazila Nirdeshika maps have been presented in Table 13 and 14.

The comparison of landuse pattern of the selected study areas (hectares) between the satellite images and Upazila Nirdeshika maps have been presented in Table 15 and 16.

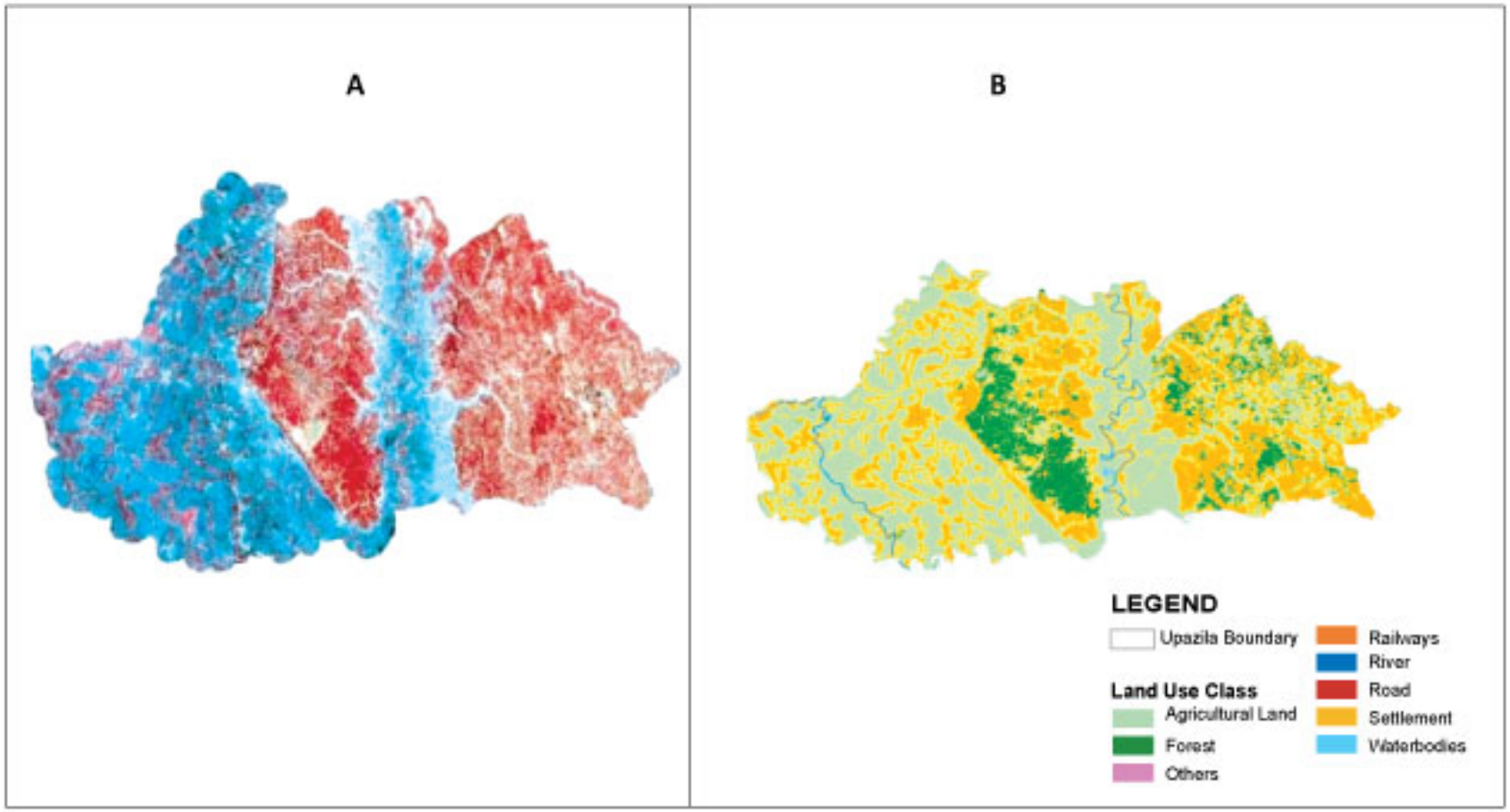


Figure 18. Satellite Image (A) and Landuse Map (B) of Ghatail Upazila

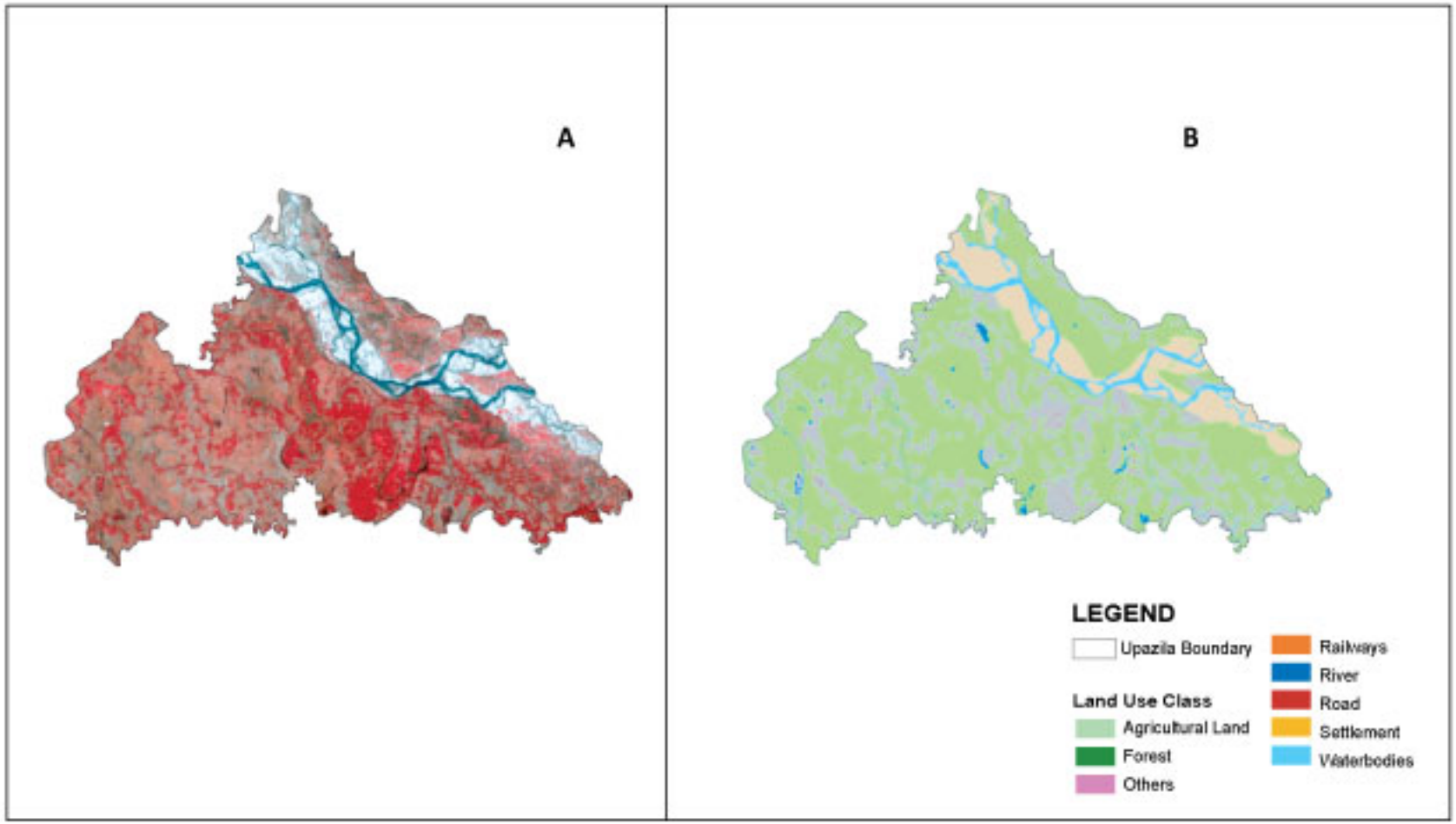


Figure 19. Satellite Image (A) and Landuse Map (B) of Gangachara Upazila

Table 13. Percentages land in the first slot study upazilas under different landuse

Class	Parbatipur		Ghatail		Tangail Sadar		Laksam		Mollahat		Bagher Para	
	Upazila Nirdeshika	Satellite images	Upazila Nirdeshika	Satellite images	Upazila Nirdeshika	Satellite images	Upazila Nirdeshika	Satellite images	Upazila Nirdeshika	Satellite images	Upazila Nirdeshika	Satellite images
Agriculture Land	95.65	82.21	92.86	52.30	76.91	67.66	78.05	62.95	80.22	67.30	70.88	67.62
Forest		1.42		9.92		0.00				0.00		
Railways		0.21				0.06		0.13		0.00		
River		0.51	1.42	0.70	6.52	5.42	0.95	0.92	3.18	0.89	0.52	0.98
Road		0.33		0.31		0.34		0.35		0.27		0.28
Settlement with homestead garden	3.79	14.53	4.62	36.53	15.59	21.03	20.88	32.78	16.6	17.78	27.43	30.73
Waterbodies	0.56	0.80	1.1	0.23	0.98	0.61	0.12	1.45		0.48	1.17	0.39
Others(weed, sand)		0.00				4.89		1.41		13.29		1.84
Char lands							0.0007	0				
Total	100	100	100	100	100	100	100	100	100	100	100	100

Table 14. Percentages land in the second slot study upazilas under different landuse

Class	Gangachara		Nachole		Nakla		Jagannathpur		Noakhali Sadar	
	Upazila Nirdeshika	Satellite images	Upazila Nirdeshika	Satellite images	Upazila Nirdeshika	Satellite images	Upazila Nirdeshika	Satellite images	Upazila Nirdeshika	Satellite images
Agriculture Land	89.18	60.6	93.98	73.77	91.52	64.96	89.12	77.93	77.01	56.45
Forest									7.15	1.56
Railways				0.08						
River	4.84	3.8	0.22	0.29	0.77	0.56	2.53	2.29	0.79	3.87
Road		0.23		0.136		0.15		0.16		0.24
Settlement with homestead garden	5.75	25.45	4.89	21.23	4.45	29.78	7.21	18.57	6.32	36.34
Water bodies	0.23	0.42	0.91	1.47	3.26	1.53	1.14	1.05		0.78
Others(weed, sand, clay)		9.77		3.02		2.99			8.73	0.75
Char lands						0				
Total	100	100	100	100	100	100	100	100	100	100

Table 15. Comparison of landuse (in Hectares) of the first slot study upazilas

Class	Parbatipur		Ghatail		Tangail Sadar		Laksam		Mollahat		Bagher Para	
	Upazila Nirdeshika	Satellite images	Upazila Nirdeshika	Satellite images	Upazila Nirdeshika	Satellite images	Upazila Nirdeshika	Satellite images	Upazila Nirdeshika	Satellite images	Upazila Nirdeshika	Satellite images
Agriculture Land	37754.72	32630	41892.63	23687	23015.17	20345	33180.87	26853	16295.07	13747	19017.38	17922.14
Forest		563.87		4493.56								
Railways		84.87				19.01		57.54				
River		200.55	639.48	318.97	1960.43	1630.11	404.44	392.74	646.48	180.89	139.76	260.51
Road		129.38		141.28		100.96		147.91		55.49		74.67
Settlement with homestead garden	1497.8	5765.67	2082.53	16547	4663.88	6323.46	8874.96	13982.9	3372.65	3632.04	7361.08	8146.21
Waterbodies	220.23	317.79	497.47	104.29	294.7	182.15	51.5	618.17		97.12	313.75	102.38
Others*(weed, sand)*						1469.63		602.27		2714.6		486.75
Char lands							0.28					
Total	39473	39692	45112	45293	29924	30070	42512	42654.5	20314	20427	26832	26506

Table 16. Comparison of landuse (in Hectares) of the second slot study upazilas

Class	Gangachara		Nachole		Nakla		Jagannathpur		Noakhali Sadar	
	Upazila Nirdeshika	Satellite images	Upazila Nirdeshika	Satellite images	Upazila Nirdeshika	Satellite images	Upazila Nirdeshika	Satellite images	Upazila Nirdeshika	Satellite images
Agriculture Land	18701	12818	26662	21607	15880	11411.8	32426	28886.2	72995	53492
Forest									6774	1476.1
Railways				24.5						
River	1015	735.1	62	85.1	133	99	920	848.9	752	3665.8
Road		48.5		39.8		27.1		57.8		231.7
Settlement with homestead garden	1205	5379	1387	6218	773	5234	2623	6885	5994	34433.8
Waterbodies	48	88.1	257	430	565	268.7	415	388		742.5
Others*(weed, sand, clay)*		2064.1		886		525			8280	711.4
Char lands										
Total	20969	21132.6	28368	29291.14	17351	17566.44	36384	37066.29	94795	94753.66

Cropping Pattern

The cropping pattern data for the study upazilas were generated based on field survey and upazila Nirdeshika data. The brief description of the cropping pattern of study upazilas are given below.

Parbatipur Upazila: The net cultivable area in this upazila is about 30,060 ha. The areas of single, double and triple cropping are about 5%, 76% and 19% of the NCA respectively. The main cropping pattern of this upazila found as Fallow – T Aman – Boro, which covers about 69.1% of the NCA. The next dominant cropping patterns are Fallow – T Aman – Rabi crops – Boro or Fallow – T Aman – Rabi crops. The coverage of these cropping pattern is about 19.6% of the NCA. Among the total Rabi crops, the area of maize, potato, wheat, mustard, chilli, spices, vegetables are about 7.7%, 7.4%, 1.7%, 1.3%, 0.4%, 0.4% and 0.3% of the NCA respectively. Details of the existing major cropping patterns are presented in Table 17.

From the field survey data it has been found that, there is a slight difference in the cropping pattern from that of the existing Upazila Nirdeshika data. According to the field data the dominant cropping pattern is Fallow-TAman -Boro covered 23.2% of the total NCA. Whereas the existing cropping pattern found from the Upazila Nirdeshika data is Fallow-T Aman-Rabi Crop (Figure 20 and Table 18).

Table 17. Existing major cropping patterns of Parbatipur upazila

Kharif-I	Kharif-II	Rabi	Area (ha)	% of NCA
Fallow	T Aman	Rabi Crops	1,990	6.6
Fallow	*T Aman*	*Boro*	*20,765*	*69.1*
Fallow	T Aman	Rabi Crops-Boro	3,910	13.0
Vegetables	T Aman	Rabi Crops	930	3.1
Jute	T Aman	Rabi Crops	800	2.7
Vegetables	Vegetables	Rabi Crops	130	0.4
Others			1,535	5.1
Total			**30,060**	**100.0**

Source: DAE, Parbatipur upazila, 2012

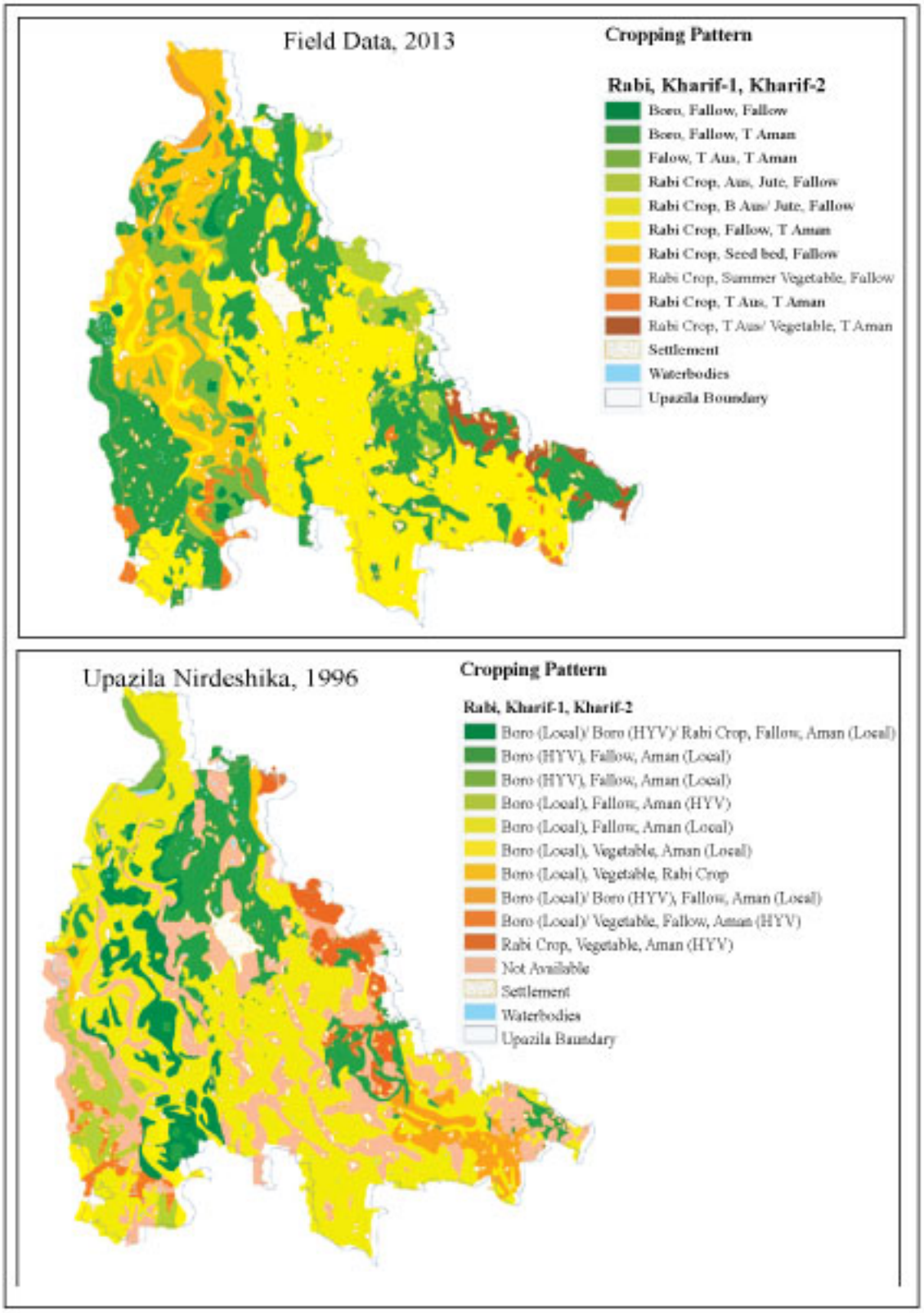


Figure 20. Cropping patterns of Parbatipur upazila according to Field Survey & Upazila Nirdesika data

Table 18. Major cropping patterns of Parbatipur upazila according to Field Survey, 2013 & Upazila Nirdeshika, 1996

Field Data, 2013			Upazila Nirdeshika data, 1996			Area (ha)	% of NCA
Kharif-I	Kharif-II	Rabi	Kharif-I	Kharif-II	Rabi		
Fallow	T Aman	Boro	TAus/ Vegetable	T Aman	Rabi Crop	634	1.7
Fallow	*T Aman*	*Boro*	*Fallow*	*T Aman*	*Rabi Crop*	*8744*	*23.2*
Fallow	T Aman	Boro	Fallow	T Aman	Boro	965	2.6
Fallow	T Aman	Boro	Seed bed	Fallow	Rabi Crop	5140	13.6
Fallow	T Aman	Boro	T Aus	T Aman	Rabi Crop	165	0.4
Fallow	T Aman	Boro (HYV)	Fallow	T Aman	Boro	5141	13.6
Fallow	T Aman	Boro (HYV)	B Aus/ Jute	Fallow	Rabi Crop	156	0.4
Fallow	T Aman	Boro (Local)/ Boro (HYV)	Fallow	T Aman	Rabi Crop	1326	3.5
Fallow	T Aman	Boro (Local)/ Boro (HYV)/ Rabi Crop	T Aus	T Aman	Fallow	2590	6.9
Fallow	T Aman (Local)/ Vegetable	Boro (HYV)	Summer Vegetable	Fallow	Rabi Crop	439	1.2
Fallow	Aman (HYV)	Boro (Local)/ Vegetable	Fallow	T Aman	Boro	446	1.2
Fallow	Aman (HYV)	Boro (Local)	Fallow	T Aman	Boro	1360	3.6
Not Available	Not Available	Not Available	Fallow	T Aman	Boro	4218	11.2
Not Available	Not Available	Not Available	Fallow	T Aman	Rabi Crop	4099	10.9
Vegetable	Rabi Crop	Boro (Local)	Fallow	T Aman	Rabi Crop	339	0.9
Vegetable	Aman (HYV)	Rabi Crop	Aus/ Jute	Fallow	Rabi Crop	1357	3.6
Vegetable	Aman (Local)	Boro (Local)	T Aus	T Aman	Rabi Crop	638	1.7
Total						37757	100

Source: Field Survey, 2013 & Upazila Nirdeshika,1996

Ghatail Upazila: The net cultivable area of this upazila is about 30,150 ha where double cropped area is dominant. About 18% of the net cultivable area is covered by the single cropping. About 68% of the NCA is occupied by double cropped and the remaining 14% is covered by triple cropped lands. A number of cropping patterns is being practiced by the farmers of this upazila on different land types. The maximum area is covered by the Fallow - T Aman-Boro cropping pattern that covers about 59% of the NCA. The second highest coverage is by perennial crops, which covers about 12% of the NCA. Among the total perennial crops, banana, pineapple, ginger and turmeric cover about 1500 ha, 1000 ha, 150 ha and 950 ha respectively. Details of the existing major cropping patterns are presented in Table 19.

The dominant cropping pattern of Ghatail upazila is Turmeric- Pineapple- Boro (HYV) according to the field survey data while it is Pineapple-Pineapple- Pineapple as stated by Upazila Nirdeshika. The area covered by this pattern is about 25.3% of the total NCA (Figure 21 and Table 20).

Table 19. Existing major cropping patterns of Ghatail upazila according to DAE

Kharif-I	Kharif-II	Rabi	Area (ha)	% of NCA
Perennial Crops	Perennial Crops	Perennial Crops	3,600	11.9
Fallow	Vegetables	Vegetables	950	3.2
Fallow	T Aman	Rabi Crops-Boro	1,170	3.9
Fallow	*T Aman*	*Boro*	*17,800*	*59.0*
Jute	T Aman	Rabi Crops/Fallow	1,670	5.5
B Aman	B Aman	Boro	1,850	6.1
Fallow	Fallow	Boro	550	1.8
Others			2,560	8.5
Total			**30,150**	**100.0**

Source: DAE, Ghatail Upazila, 2012

Table 20. Major cropping patterns of Ghatail upazila according to Field Survey, 2013 & Upazila Nirdeshika, 1985

Field Survey data, 2013			Upazila Nirdeshika, 1985			Area (ha)	% of NCA
Kharif-I	Kharif-II	Rabi	Kharif-I	Kharif-II	Rabi		
Fallow	Aman (HYV)/ Aman (Local)	Boro (HYV)	Timber	Timber	Timber	1876	4.5
Fallow	Aman (HYV)	Boro	Fallow	T Aman (HYV)	Boro (HYV)	1881	4.5
T Aus	T Aman	Boro (HYV)	Fallow	T Aman (HYV)	Boro (HYV)	3884	9.3
Fallow	Aman (HYV)	Boro (HYV)	Fallow	Fallow	Boro (HYV)	715	1.7
Fallow	Aman (HYV)	Boro (HYV)	Fallow	T Aman (HYV)	Boro (HYV)	2806	6.7
Fallow	T Aman	Boro (HYV)	Fallow	T Aman (HYV)	Boro (HYV)	658	1.6
Fallow	T Aman	Boro (HYV)	Fallow	Fallow	Boro (HYV)	320	0.8
Fallow	T Aman	Boro (HYV)	Fallow	T Aman (HYV)	Boro (HYV)/ Mustard(Tori-7)	2165	5.2
Fallow	T Aman	Boro (HYV)/ Boro(Local)	Fallow	T Aman (HYV)	Boro (HYV)	391	0.9
Not Available	Not Available	Not Available	Fallow	T Aman (HYV)	Boro (HYV)	2745	6.6
Not Available	Not Available	Not Available	Fallow	Fallow	Boro (HYV)	2466	5.9
Not Available	Not Available	Not Available	Fallow	T Aman (HYV)	Boro (HYV)/ Mustard	1270	3.0
Not Available	Not Available	Not Available	B Aus (Local)/ Jute	T Aman (HYV)	Rabi Crop	1017	2.4
Not Available	Not Available	Not Available	Boro (HYV)	T Aman (HYV)	Mustard (Tori-7)	263	0.6
Not Available	Not Available	Not Available	Fallow	T Aman (HYV)	Boro (HYV)	3516	8.4
Not Available	Not Available	Not Available	Fallow	Fallow	Boro (HYV)	2872	6.9
Turmeric	*Pineapple*	*Boro (HYV)*	*Pineapple*	*Pineapple*	*Pineapple*	*10588*	*25.3*
Turmeric	T Aman	Boro (HYV)	B Aus/ Jute	Fallow	Rabi Crop	1610	3.8
Vegetable	T Aman	Boro (HYV)/ Vegetable	B Aus (Local)	Fallow	Rabi Crop	850	2.0
Total						**41893**	**100**

Source: Field Survey, 2013 & Upazila Nirdeshika, 1985

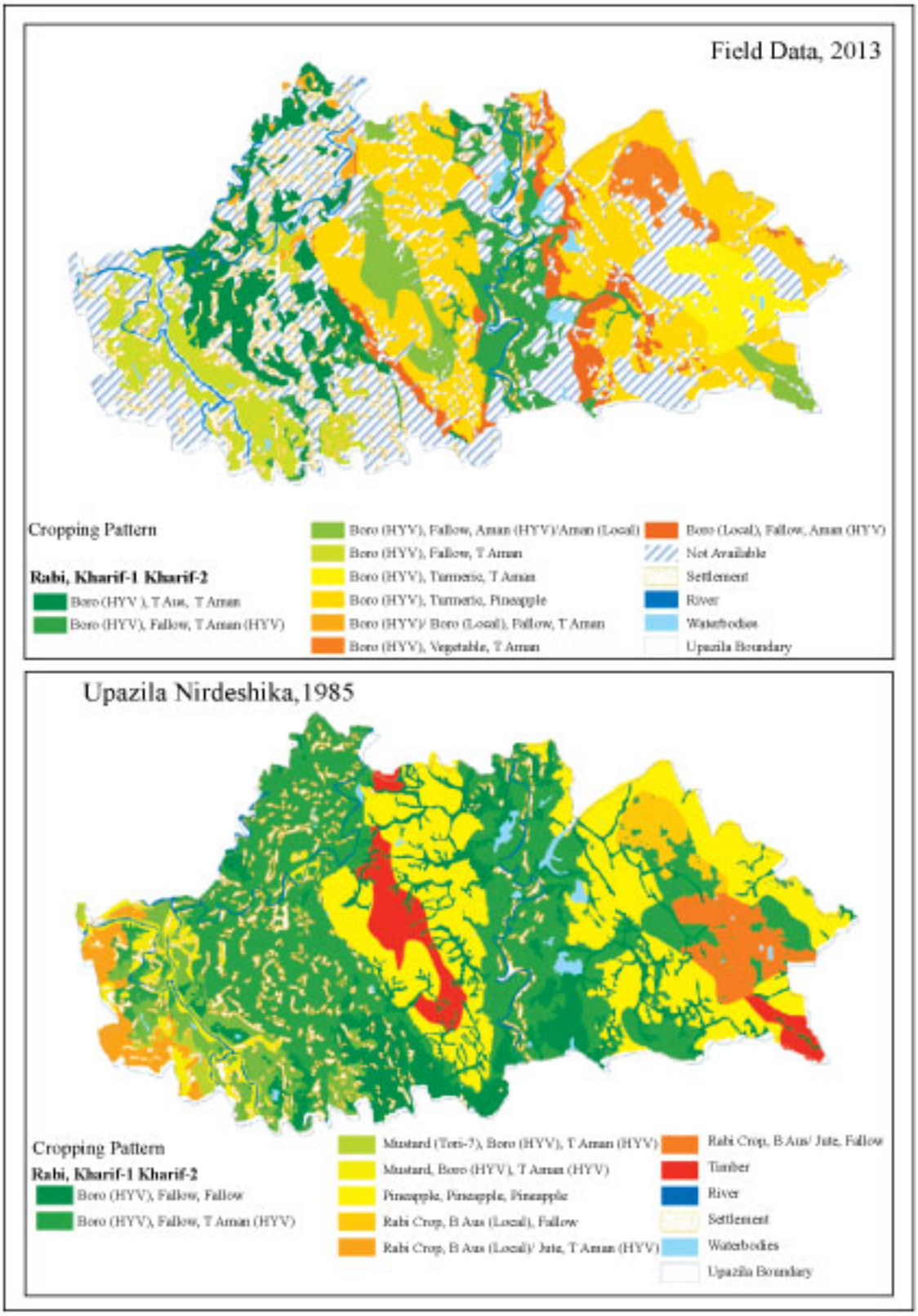


Figure 21. Cropping patterns of Ghatail upazila according to Field Survey & Upazila Nirdeshika

Tangail Sadar Upazila: The net cultivable area of this upazila is about 20,465 ha. Single, double and triple cropped patterns are practiced in about 16%, 55% and 30% of the NCA respectively. The main cropping pattern is Fallow- Fallow-Rabi crops-Boro which occupies about 20.1% of the NCA. The other major cropping patterns are Fallow-Fallow-Boro, Fallow-T Aman-Rabi crops-Boro, Fallow-T Aman-Boro and Jute-T Aman-Boro, which cover about 12.4%, 11.6%, 11.2% and 11.6% of the NCA respectively. The area of Rabi crops, such as mustard, pulses, potato, spices, vegetables, wheat, sweet potato and maize are about 21.6%, 20.9%, 3.4%, 2.2%, 9.4%, 4.8%, 1.6% and 0.1% of the NCA respectively. Very limited area is covered with single perennial crops like banana (150 ha), papaya (45 ha), sugarcane (400 ha), ginger (60 ha) and turmeric (45 ha). Details of the existing major cropping patterns are presented in Table 21.

Table 21. Existing major cropping patterns of Tangail Sadar upazila

Kharif-I	Kharif-II	Rabi	Area (ha)	% of NCA
Perennial Crops	Perennial Crops	Perennial Crops	700	3.4
Jute	T Aman	Rabi Crops	1,130	5.5
Fallow	T Aman	Rabi Crops-Boro	2,370	11.6
Fallow	T Aman	Boro	2,290	11.2
Jute	Fallow	Rabi Crops	2,370	11.6
Sesame/Jute/Vegetables/Fallow	Vegetables/Fallow	Rabi Crops	1,885	9.2
B Aus	B Aman	Rabi Crops-Boro	1,245	6.1
B Aus	B Aman	Boro	1,835	9.0
Fallow	*Fallow*	*Rabi Crops-Boro*	*4,105*	*20.1*
Fallow	Fallow	Boro	2,535	12.4
Total			20,465	100.0

Source: DAE, Tangail Sadar Upazila, 2012

The field survey data reveals that, there is some difference in the cropping pattern from the existing Upazila Nirdeshika. According to the field data the dominant cropping pattern is Jute- T Aman Boro (HYV) has covered 23.8% of the total NCA. Whereas the existing cropping pattern found from the Upazila Nirdeshika is B Aus-T Aman-Rabi Crop (Figure 22 and Table 22).

Table 22. Major cropping patterns of Tangail Sadar upazila according to Field Survey, 2013 &Upazila Nirdeshika, 1992

Field survey Data, 2013			Upazila Nirdeshika, 1992			Area (ha)	% of NCA
Kharif-I	**Kharif-II**	**Rabi**	**Kharif-I**	**Kharif-II**	**Rabi**		
Aus (HYV)	Fallow	Mustard	Fallow	Fallow	Boro (HYV)	2591	11.3
T Aus	T Aman	Boro (HYV)	T Aus	Vegetable	Boro (HYV)	506	2.2
Fallow	Seed Bed	Boro (HYV)	Aus/Jute	Fallow	Rabi Crop	220	1.0
Fallow	T Aman	Boro (HYV)	Aus/Jute	Fallow	Rabi Crop	2322	10.1
Fallow	T Aman	Boro (HYV)	Fallow	Fallow	Boro (HYV)	96	0.4
Fallow	T Aman	Boro (HYV)	T Aus	Fallow	Boro (HYV)	628	2.7
Fallow	T Aman	Boro (HYV)/ Mustard	Aus/Jute	Fallow	Rabi Crop	190	0.8
Fallow	Pulse	Boro (HYV)/ Mustard	Aus/Jute	Fallow	Rabi Crop	958	4.2
Fallow	Fallow	Boro (Local)/ Mustard/ Pulse	Aus/Jute	Fallow	Rabi Crop	2027	8.8
Fallow	Mustard	Boro (HYV)	Aus/Jute	T Aman	Rabi Crop	353	1.5
Fallow	Aman(HYV)	Boro (HYV)	Fallow	T Aman	Boro (HYV)	746	3.2
Jute	Fallow	Boro (HYV)/Pulse	Aus/Jute	Fallow	Rabi Crop	588	2.6
Jute	*T Aman*	*Boro (HYV)*	*B Aus*	*T Aman*	*Rabi Crop*	*5481*	*23.8*
Jute/Aus	*T Aman*	Boro *(HYV)*	Aus/Jute	Fallow	Rabi Crop	1393	6.1
Not Available	Not Available	Not Available	Fallow	Fallow	Boro (HYV)	544	2.4
Not Available	Not Available	Not Available	Fallow	T Aman	Boro (HYV)	599	2.6
Sugarcane	Sugarcane	Vegetable	Aus/Jute	Fallow	Rabi Crop	3774	16.4
Total						**23016**	**100**

Source: Field Survey, 2013 & Upazila Nirdeshika, 1992

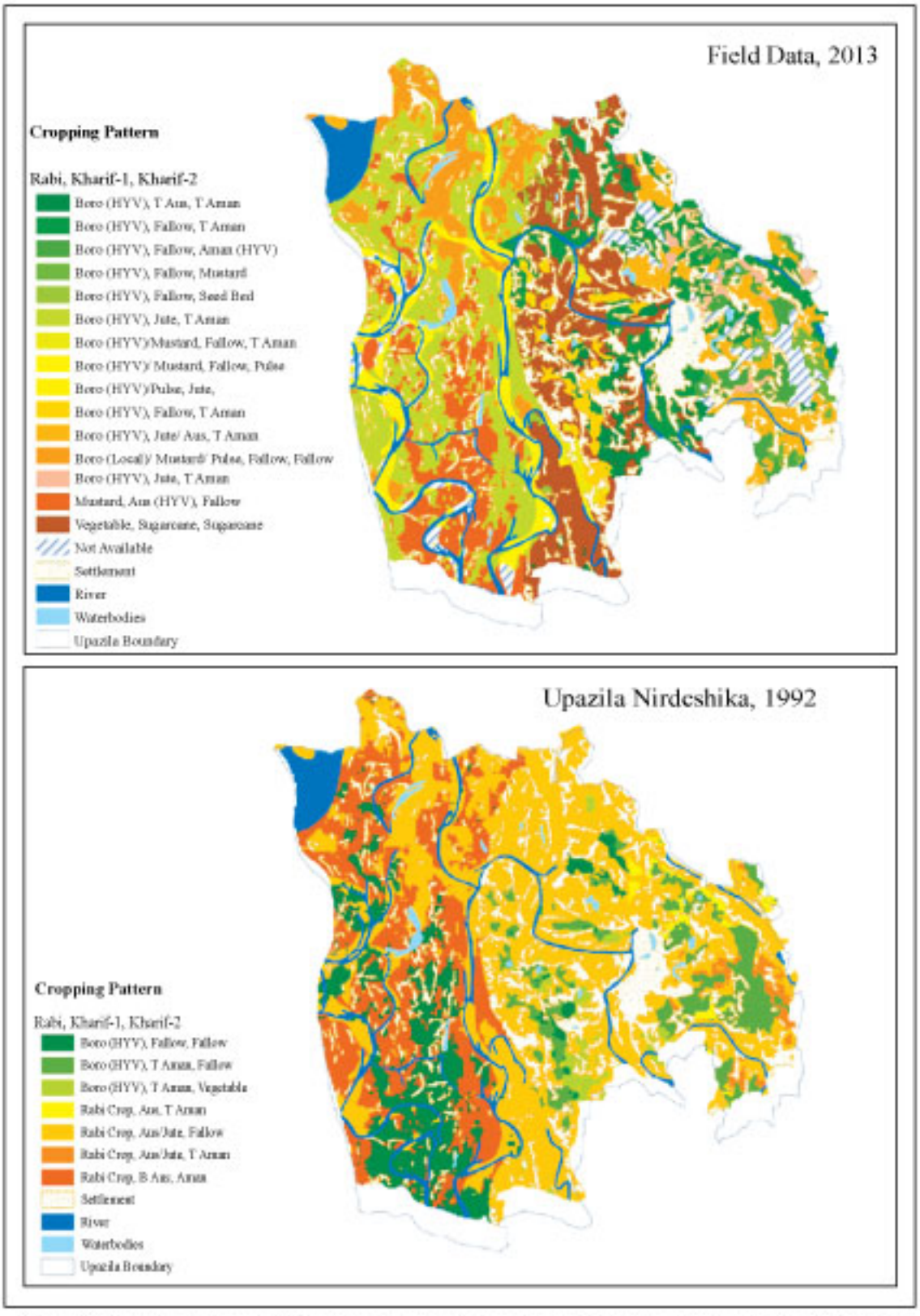


Figure 22. Cropping patterns of Tangail Sadar upazila according to Field Survey & Upazila Nirdeshika data

Laksam Upazila: In Laksam upazila, the net cultivable area is about 11,010 ha, where triple cropping pattern is dominant. Single, double and triple cropping are practiced in this upazila are about 8%, 36% and 55% of the NCA respectively. More than three crops in a year cover only about 1% of the NCA (Table 23).

Table 23. Existing major cropping patterns of Laksam upazila according to DAE

Kharif-I	Kharif-II	Rabi	Area (ha)	% of NCA
B. Aman	Fallow	Boro	989	8.98
Fallow	Fallow	Boro	928	8.43
Dhaincha	Fallow	Boro	929	8.44
Vegetable	T Aman	Boro	1010	9.17
T Aus	*T Aman*	*Boro*	*1876*	*17.04*
Fallow	T Aman	Boro	1455	13.22
T Aus	T Aman	Rabi Crops	951	8.64
Perennial Crops	Perennial Crops	Perennial Crops	2	0.02
T Aus	T Aman	Vegetable	952	8.65
T Aus	T Aman	Vegetable	951	8.64
Vegetable	Vegetable	Vegetable	15	0.13
T Aus	T Aman	Rabi Crops	951	8.64
Total			**11,010**	**100.00**

Source: DAE, Laksam Upazila, 2012

According to the field survey data, there is a difference in the cropping pattern from the existing Upazila Nirdeshika. According to the field data the dominant cropping pattern is Fallow-T Aman -Boro (HYV) which covers about 41.6% of the total NCA. Whereas the existing cropping pattern found from the Upazila Nirdeshika is B Aus-B Aman-Fallow (Figure 23 & Table 24).

Table 24. Major cropping patterns of Laksam upazila according to Field Survey, 2013 & Upazila Nirdeshika 1985

Field survey Data, 2013			Upazila Nirdeshika, 1985			Area (ha)	% of NCA
Kharif-I	Kharif-II	Rabi	Kharif-I	Kharif-II	Rabi		
T Aus	T Aman	Boro (HYV)	B Aus/ T Aus	T Aman	Fallow	83	0.3
Not Available	Not Available	Not Available	B Aus/ T Aus	T Aman	Fallow	5	0.01
T Aus (Local)	T Aman	Boro (HYV)	B Aus/ T Aus	T Aman	Rabi crops	665	2.0
Aus (Local)/ Aus (HYV)	T Aman	Boro (Local)	T Aus	Fallow	Boro/ Rabi crops	13034	39.3
Fallow	Fallow	Boro (HYV)	Fallow	Fallow	Boro	829	2.5
Fallow	T Aman	Boro (HYV)	Fallow	B Aman	Fallow	766	2.3
Fallow	*T Aman*	*Boro (HYV)*	*B Aus*	*B Aman*	*Fallow*	*13799*	*41.6*
Fallow	T Aman	Boro (HYV)	B Aus	Fallow	Fallow	3609	10.9
Fallow	T Aman	Boro (HYV)	Fallow	B Aman	Rabi crops	385	1.2
Total						**33175**	**100**

Source: Field Survey, 2013 & Upazila Nirdeshika data, 1985

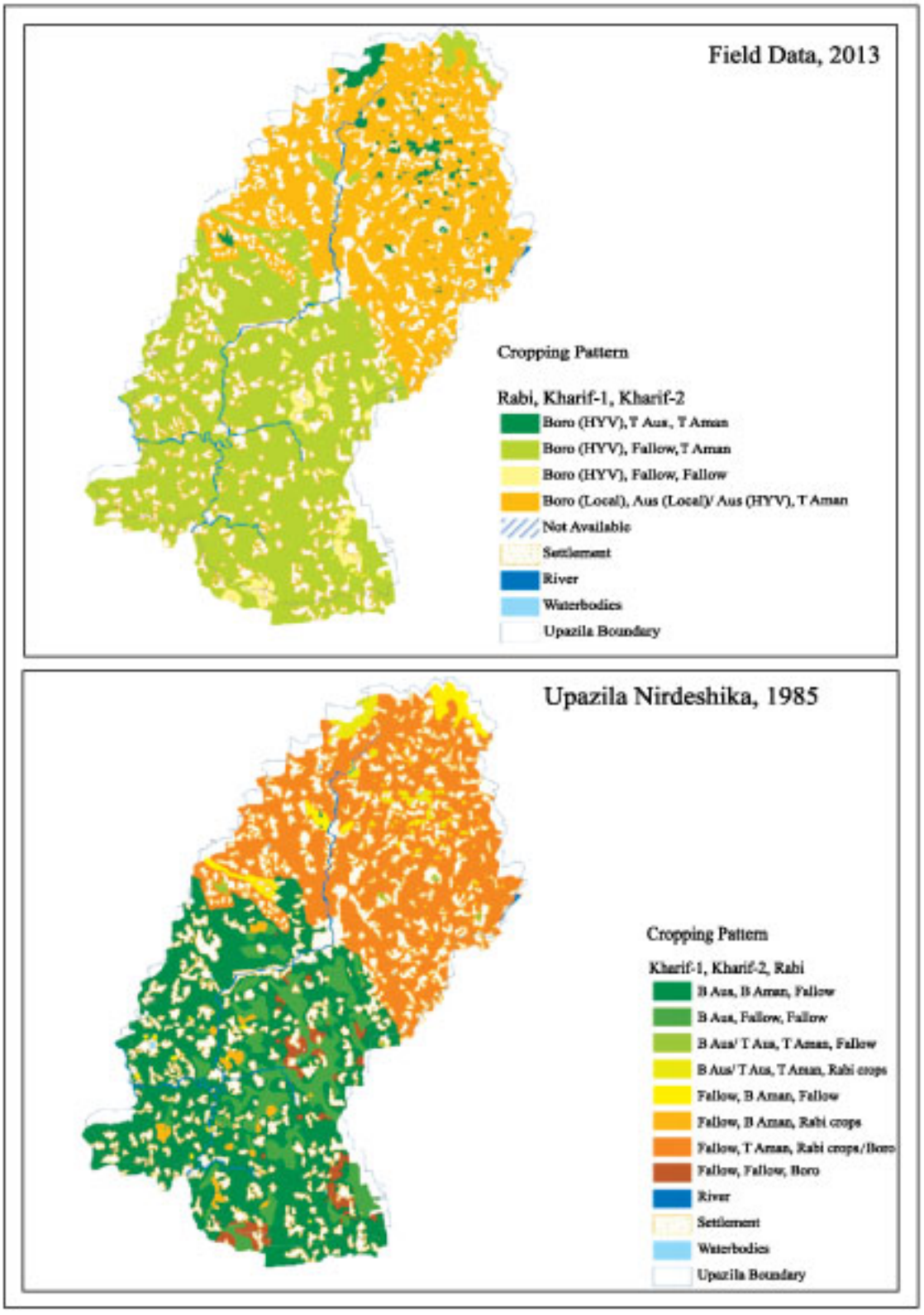


Figure 23. Cropping patterns of Laksam upazila according to Field Survey & Upazila Nirdeshika data

Mollahat Upazila: The net cultivable area of this upazila is about 12,130 ha. Single, double and triple cropping patterns are practiced in this upazila which are about 38%, 45% and 16% of the NCA respectively. The main cropping pattern is Fallow – Fallow – Boro which covers about 31.7% of the NCA. The other prominent cropping patterns are Broadcast Aus – Fallow – Boro, B Aus – B Aman – Boro, Fallow – T Aman-Rabi crops and Jute – T Aman – Rabi crops which cover about 22.1%, 11.5%, 8.8% and 6.2% of the NCA respectively. Among the Rabi crops, the percentage of coverage of pulses, vegetables, mustard, spices and wheat is about 10%, 7%, 6%, 1% and 1% of the NCA respectively. Details of the existing major cropping patterns are presented in Table 25.

Table 25. Existing major cropping patterns of Mollahat upazila

Kharif-I	Kharif-II	Rabi	Area (ha)	% of NCA
Sugarcane	Sugarcane	Sugarcane	800	6.6
Jute/Sesame	T Aman	Rabi Crops	746	6.2
Jute/Pulses/Vegetables	Vegetables	Rabi Crops	921	7.6
Vegetables	Fallow/T Aman	Rabi Crops/Fallow	314	2.6
B Aus	*Fallow*	*Boro*	*2,686*	22.1
Fallow	T Aman	Rabi Crops	1,069	8.8
Fallow	T Aman	Boro	354	2.9
B Aus	B Aman	Boro/Fallow	1,400	11.5
Fallow	Fallow	Boro	3,840	31.7
Total			12,130	100.0

Source: DAE, Mollahat, Upazila, 2012

From the field survey data it is found that, there is a slight difference in the cropping pattern from the existing Upazila Nirdeshika. According to the field data the dominant cropping pattern is Fallow-Fallow – Boro (HYV) which covers 49.6% of the total NCA. Whereas the major existing cropping pattern found from the Upazila Nirdeshika is Fallow – B Aman – Fallow (Figure 24 and Table 26).

Table 26. Major cropping patterns of Mollahat upazila according to Field Survey, 2013 & Upazila Nirdeshika, 1986

Field survey Data, 2013			Upazila Nirdeshika, 1986			Area (ha)	% of NCA
Kharif-I	**Kharif-II**	**Rabi**	**Kharif-I**	**Kharif-II**	**Rabi**		
Aus	T Aman Pulse	Boro(HYV)	Aus/ Jute	Fallow	Fallow	222	1.4
Aus	Bettel Leaf	Boro (HYV)	B Aus/ Jute/ Sesames	T Aman	Fallow	1948	12.0
Fallow	T Aman	Boro(HYV)	Aus	T Aman	Rabi crops	278	1.7
Fallow	Fallow	Boro (HYV)/ Shrimp	B Aus	Aman	Rabi crops	780	4.8
Fallow	*Fallow*	*Boro (HYV)*	*Fallow*	*B Aman*	*Fallow*	8075	49.6
Not Available	Not Available	Not Available	Aus/ Jute	T Aman	Rabi crops	13	0.1
Not Available	Not Available	Not Available	Aus/ Jute	Fallow	Rabi crops	536	3.3
Not Available	Not Available	Not Available	B Aus/ Jute/Cesams	B Aman	Fallow	1238	7.6
Not Available	Not Available	Not Available	Aus	T Aman	Fallow	590	3.6
Not Available	Not Available	Not Available	Fallow	B Aman	Fallow	208	1.3
Pulse/ Mustard	T Aman	Boro (HYV)	B Aus/ Jute/Cesams	B Aman	Rabi crops	2255	13.8
Vegetable	T Aman	Boro(HYV)	Aus/ Jute	Fallow	Rabi crops	151	0.9
Total						**16294**	**100**

Source: Field Survey, 2013 & Upazila Nirdeshika data, 1986

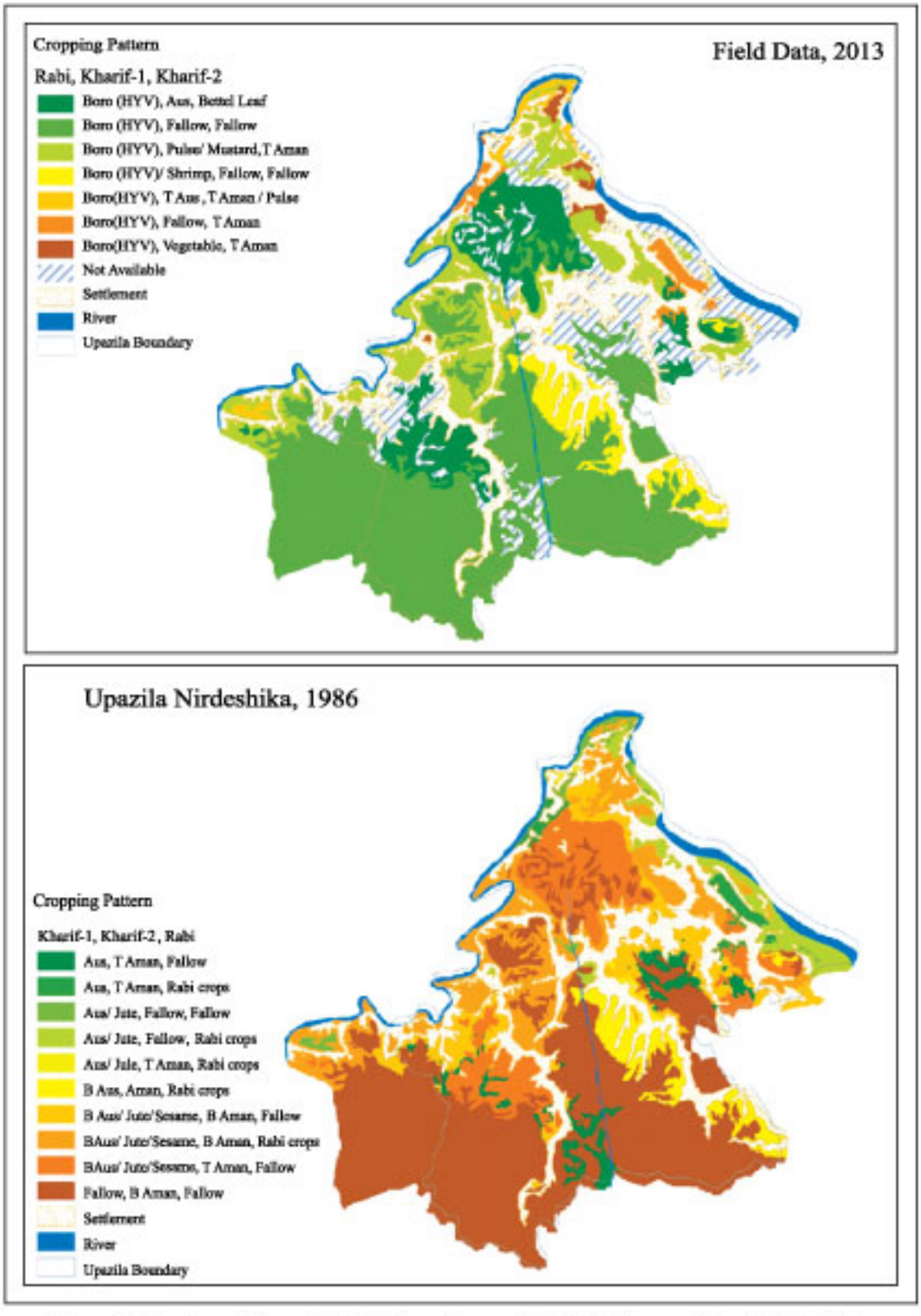


Figure 24. Cropping patterns of Mollahat upazila according to Field Survey & Upazila Nirdeshika

Bagher Para Upazila: According to the information of DAE, in Bagher Para upazila, the net cultivable area is about 19,020 ha. Double and triple cropped areas are almost equally dominant in this upazila. The maximum area is covered by Fallow - T Aman –Rabi Crops/ Boro pattern that covers about 50.1% of the NCA. The second highest cropping pattern is Vegetable - T Aman –Rabi Crops/ Boro, which covers about 19.6% of the NCA. Details of the existing major cropping patterns are presented in Table27.

Table 27. Existing major cropping patterns of Bagher Para upazila according to DAE

Kharif-I	Kharif-II	Rabi	Area (ha)	% of NCA
Fallow	*T Aman*	*Rabi Crops- Boro*	*9525*	*50.1*
Vegetable	T Aman	Rabi Crops- Boro	3720	19.6
Jute	T Aman- Pulse	Rabi Crops- Boro	3120	16.4
T Aus	Fallow	Rabi Crops- Boro	670	3.5
Vegetable	Vegetable	Vegetable	500	2.6
T Aus	T Aman	Rabi Crops- Boro	420	2.2
Perennial Crops	Perennial Crops	Perennial Crops	305	1.6
Sesame	T Aman	Rabi Crops- Boro	270	1.4
Pulse	T Aman-Vegetable	Rabi Crops- Boro	210	1.1
T Aus	Vegetable	Rabi Crops- Boro	150	0.8
Vegetable	T Aman	Vegetable	70	0.4
Vegetable	Vegetable	Rabi Crops- Boro	50	0.3
Fallow	Fallow	Rabi Crops- Boro	10	0.1
Total			**19020**	**100**

Source: DAE, Bagher Para Upazila, 2013

From the field survey data it was found that, there is a slight change in the cropping pattern from the existing Upazila Nirdeshika. According to the field data the dominant cropping pattern is Fallow – T Aman – Boro (HYV) that covered 41.8% of the total NCA. Whereas the existing cropping pattern found from the Upazila Nirdeshika is Fallow – T Aman – Boro (HYV) (Figure 25 and Table 28).

Table 28. Major cropping patterns of Bagher Para upazila according to Field Survey, 2013 &Upazila Nirdeshika, 1996

Field Survey, 2013			Upazila Nirdeshika, 1996			Area (ha)	% of NCA
Kharif-I	Kharif-II	Rabi	Kharif-I	Kharif-II	Rabi		
T Aus	Fallow	Boro(Local)/ Mustard	Aus	T Aman	Fallow	44	0.2
T Aus	T Aman	Boro (HYV)	Aus/ Jute	T Aman	Fallow	5646	29.7
T Aus	T Aman	Boro (HYV)	Aus	T Aman	Fallow	1240	6.5
Fallow	T Aman Mustard	Boro (HYV)/ Mustard	Aus/ Jute	T Aman	Fallow	972	5.1
Fallow	*T Aman*	*Boro (HYV)*	*Fallow*	*T Aman*	*Boro (HYV)*	*7954*	*41.8*
Fallow	T Aman	Boro (HYV)	Fallow	Fallow	Boro (HYV)	1653	8.7
Not Available	Not Available	Not Available	Aus/ Jute	T Aman	Fallow	842	4.4
Total						**19018**	**100.0**

Source: Field Survey, 2013 & Upazila Nirdeshika, 1996

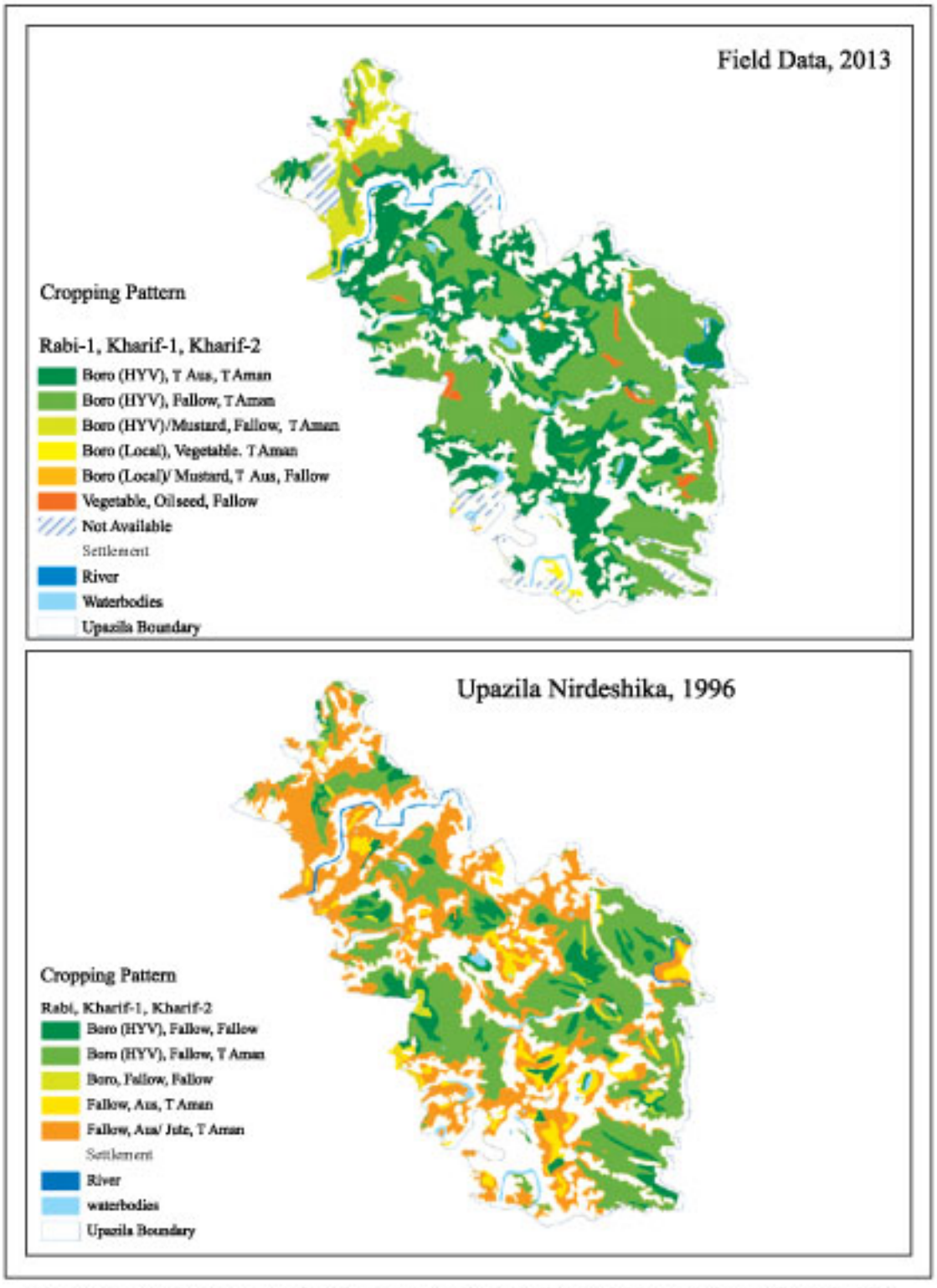


Figure 25. Cropping patterns of Bagher Para upazila according to Field Survey & Upazila Nirdeshika

General Information about the Respondent Farmers

A semi-structured survey is conducted among 255+65=320 farmer respondents from all the selected upazilas. The general information collected through the questionnaire survey included the pattern of household size, area of crop land, season-wise crop yield, cost of crop production etc. described in the baseline section under methodology. A major part of the questionnaire survey was collection of socio-economic data. During the survey, farmers were interviewed to document their responses in socio-economic aspects.

Pattern of Household Size and Area of Cropland: It is observed that (Figure 26) more than 50% of the farmers have a household with 4 to 6 members and only 7% have 1 to 3 members. The survey presented that (Figure 27) 74% of the farmers have croplands between 0.02 to 1.01 hectares and only 6% have more than 3.03 hectares. More than 17% of the farmers obtained above 3.0 metric ton of crop yield in the Kharif-1 season, whereas 45% of the farmers obtained the same yield in the Kharif-2 season. A huge proportion, around 88% of the respondents, gets above 3.0 metric tons of crop yield per hectare in the Rabi season.

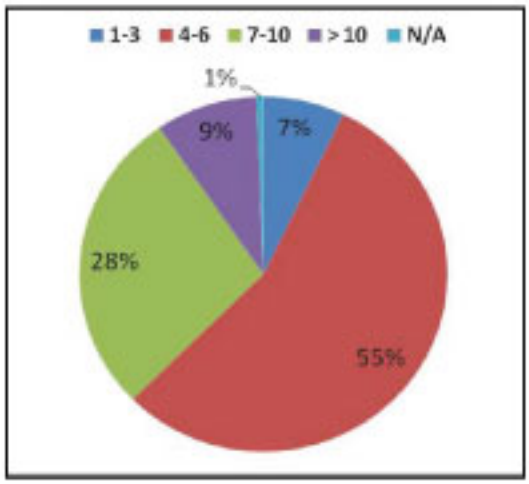


Figure 26. Pattern of household size of farmers (no. of members)

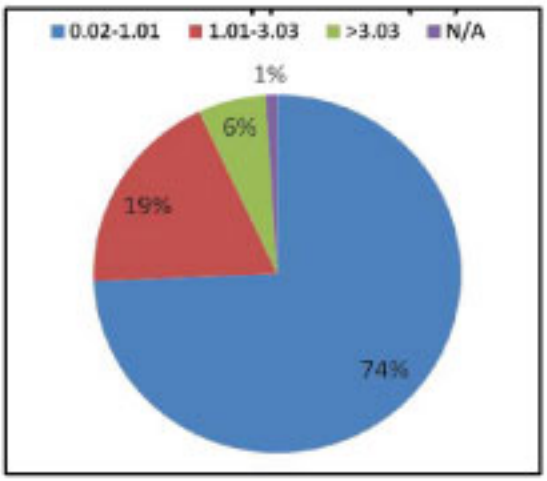


Figure 27. Area of cropland (hectare) of the farmers

Product demand and product price: The survey found that 83% of farmers reported that the product demand was very high to high. Conversely, more than 62% of farmers said that the product price was low to very low (Figure 28).

Farmers generally use both formal and informal credit for crop production purposes However, about 56% and 39% of the farmers responded that they do not use formal or informal credit respectively.

Cost of crop production: Besides biophysical conditions, the cost of crop production is undoubtedly important for crop suitability assessment. From Figure 29, It is noted that about 95% of the farmers responded that the cost of production was high to very high. Only 4% of farmers reported that the cost of production was fair to low. Because of high production cost and lower price of their products, the farmers were found reluctant to produce more. In many cases they were either reducing the coverage or switching to other crops especially in case of boro paddy cultivation.

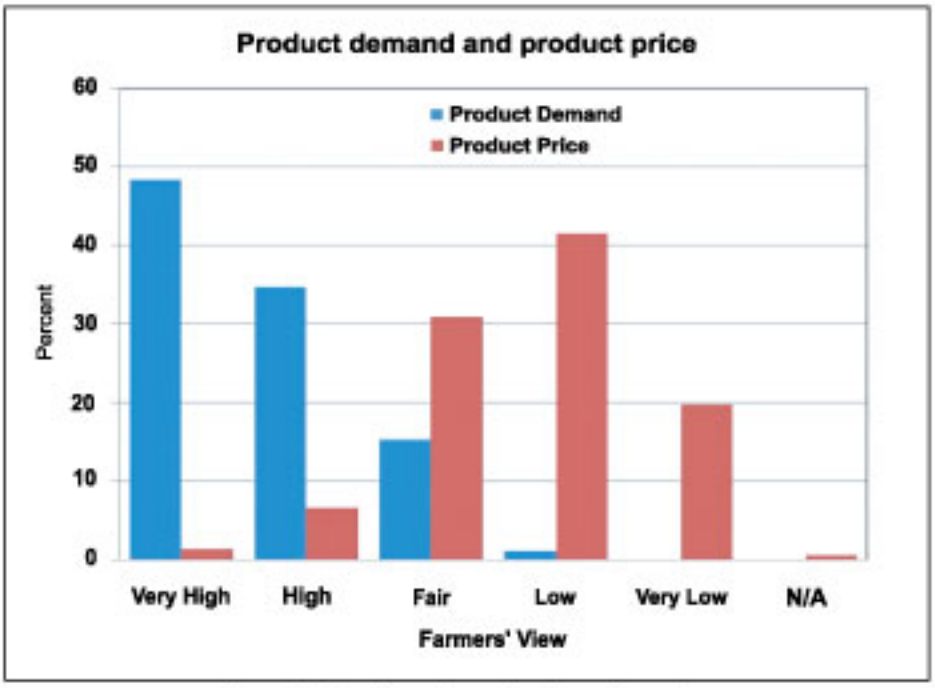


Figure 28. Product demand and product price

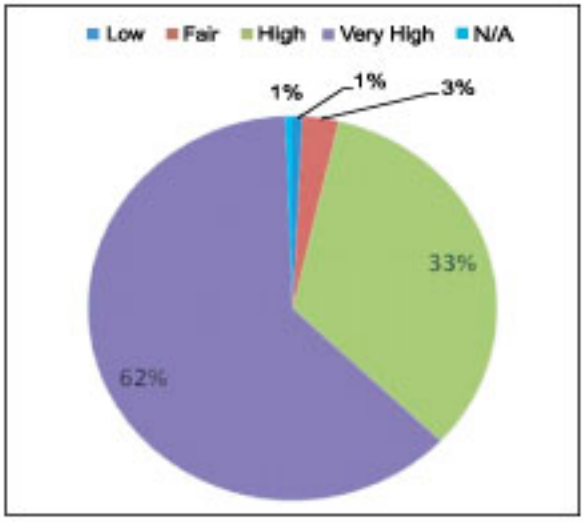


Figure 29. Respondents' View on Cost of Crop Production

Availability of labourer: Availability of agricultural labourer is very important especially at the time of land preparation and sowing/transplanting and harvesting seasons. The following Figure 30 depicts the state on the availability of labourer. Around 52 t0 65% respondents have said that availability of labourers are high to very highly during the both sowing and harvest period. On the other hand, around 10-12% respondents have said that labourers are available in a range of low to very low.

Cost of hiring labourer: The cost of labourer hiring is as an important factor in the cost of crop production. Figure 31 shows the information on the cost of labourer hiring. More than 60% farmers responded that cost of hiring labourers are high to very high during both the sowing and harvest

seasons. Conversely, only 3% farmers have said that labour cost is in a range of low to very low. About 32% farmers thought that female labourer's cost is low to very low. Around 16% farmers said that female labourer's cost is high to very high. Around 45% farmers said that female labourers are not available.

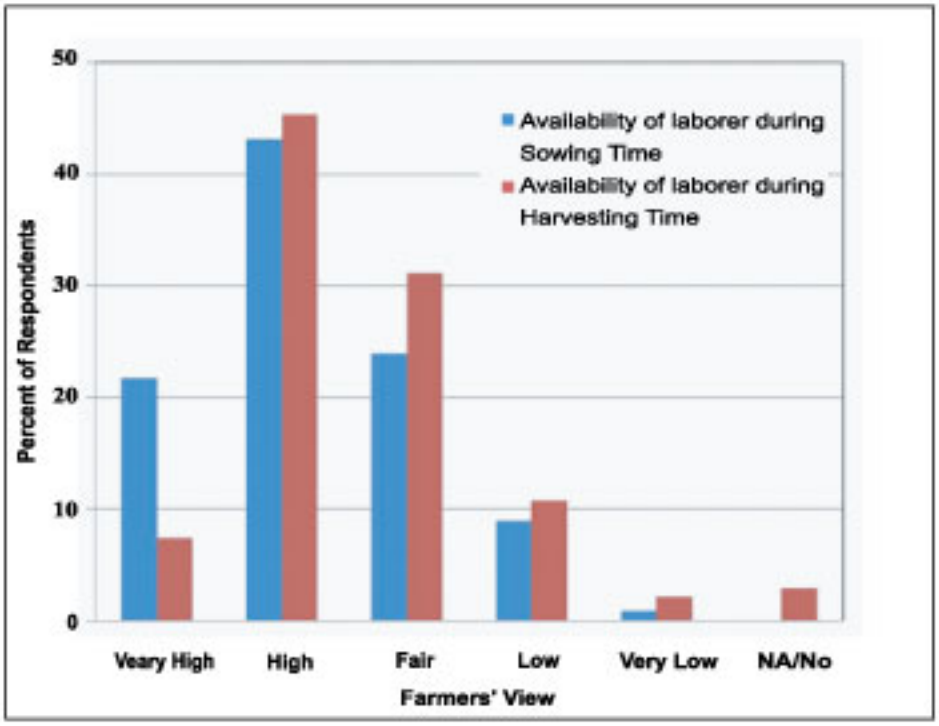


Figure 30. Availability of labourer

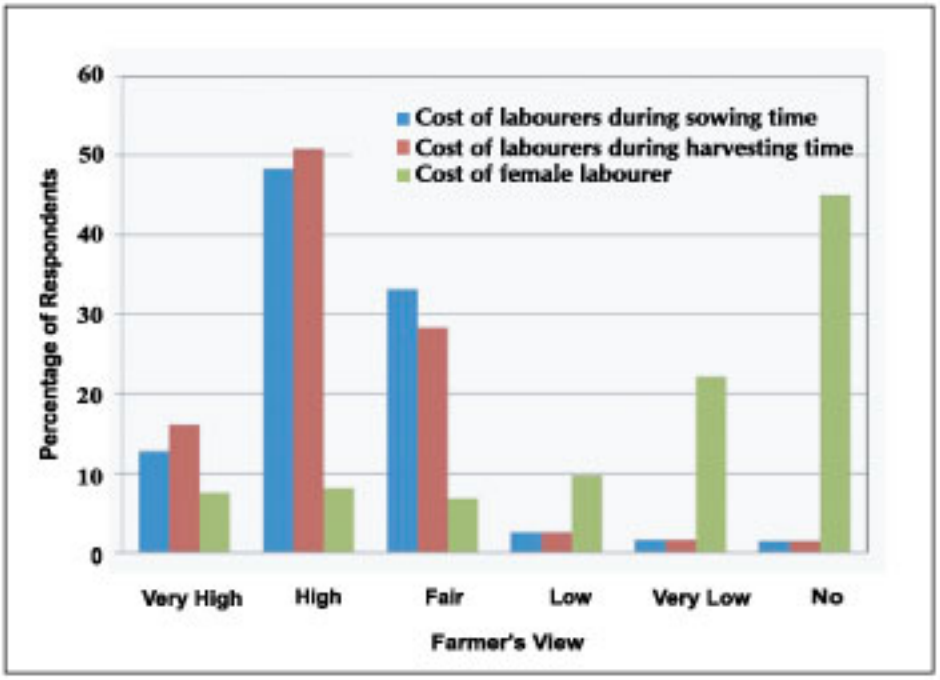


Figure 31. Cost of hiring labourer

Use of Capital intensive technology: It is important for the crop production to the use of capital intensive technology. In Figure 32 the information on use of capital intensive technology has been given. About 71% responded that use of capital intensive technology is high to very high.

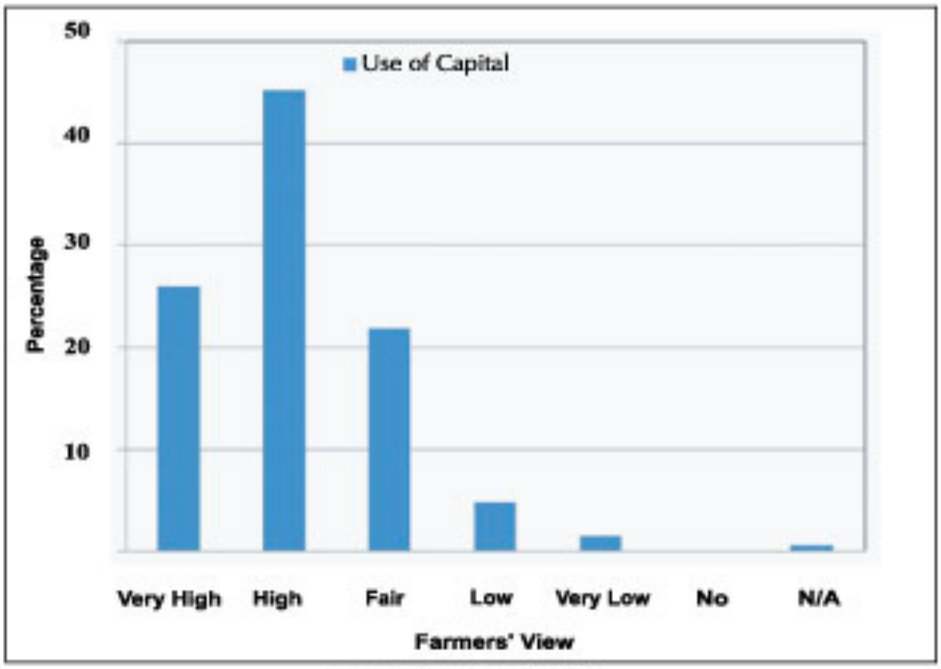


Figure 32. Use of Capital

Availability of fertilizer, electricity and water for irrigation: Availability of fertilizer, electricity and water for irrigation are three major factors which influences the crop production. As Bangladesh is a developing country, the farmers often face the scarcity of fertilizer and electricity which has adverse impacts on crop production. In addition, irrigation water also becomes inadequate due to many different factors. Therefore, the farmers were asked about the availability of fertilizer, electricity and water for irrigation to understand the current scenario. According to the responses of the farmers, the availability of fertilizer and electricity is represented in Figure 33. According to this figure, around 75% of the farmers thought that fertilizer availability was good to excellent. In addition, 9% of the farmers considered that fertilizer availability was fair. Approximately 75% of farmers reported that the availability of electricity was good to excellent and 15% of them thought that it was moderate.

On the other hand, 47% of the respondents reported that availability of water is in the range of good to excellent, whereas 32% of them said it was moderately available. However, 19% of the farmers claimed that availability of water is very poor to poor. In short, it can be said from the analysis that among these three factors electricity is most scarce and fertilizer is least scarce.

Cost of fertilizer & pesticides: The cost of pesticides and fertilizer controls the cost of production. From the Figure 34 it can be seen that only 33% of farmers thought that the cost of pesticides was fair. Conversely, around 62% of farmers said that the cost was in a range of high to very high. On the other hand, a considerable portion (79%) of the farmers said that the cost of fertilizer was high to very high, while only 17% of them said that the cost of fertilizer was fair. Only 1% of the respondent farmers reported the cost of fertilizer as low.

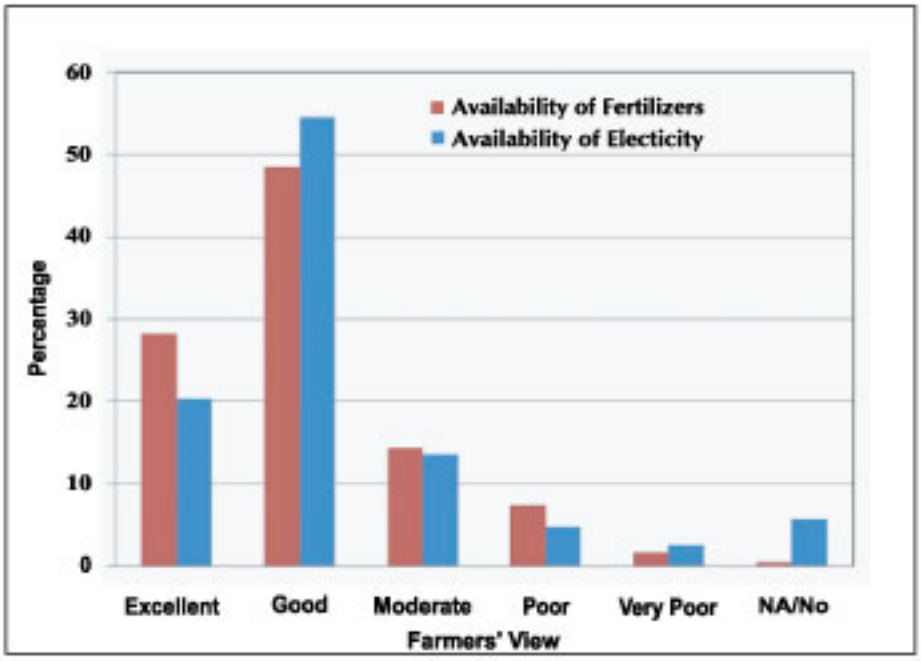


Figure 33. Availability of Fertilizers and Electricity

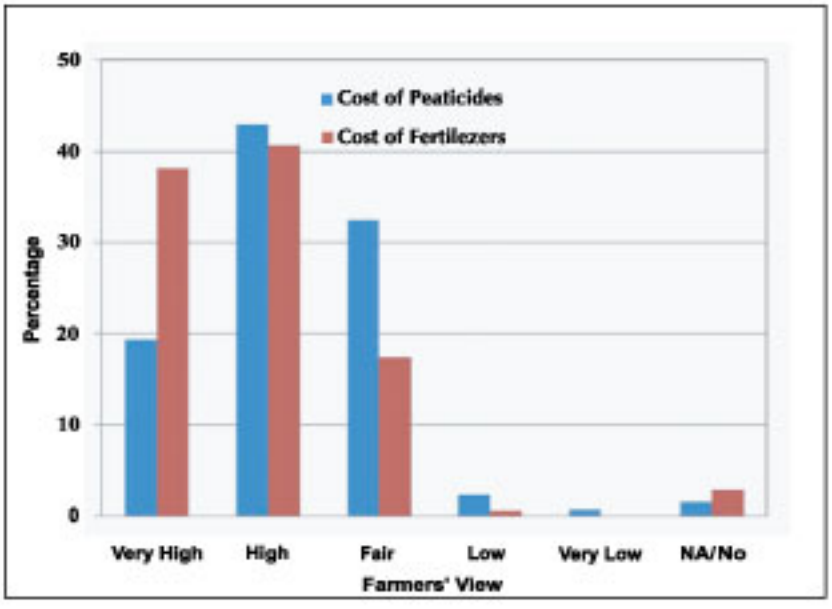


Figure 34. Cost of Fertilizers and Pesticides

Transport cost: Transport cost always affects the cost of crop production. The information on the transport cost both field to home and home to market have been provided in the Figure 35. Around 28 to 36% farmers have replied that transport cost is high to very high from field to home and home to market respectively. Moreover, only 11 to 15% farmers have responded that transport cost (both field to home and home to market) is low to very low. A substantial number of farmers (38%) did not answer the question.

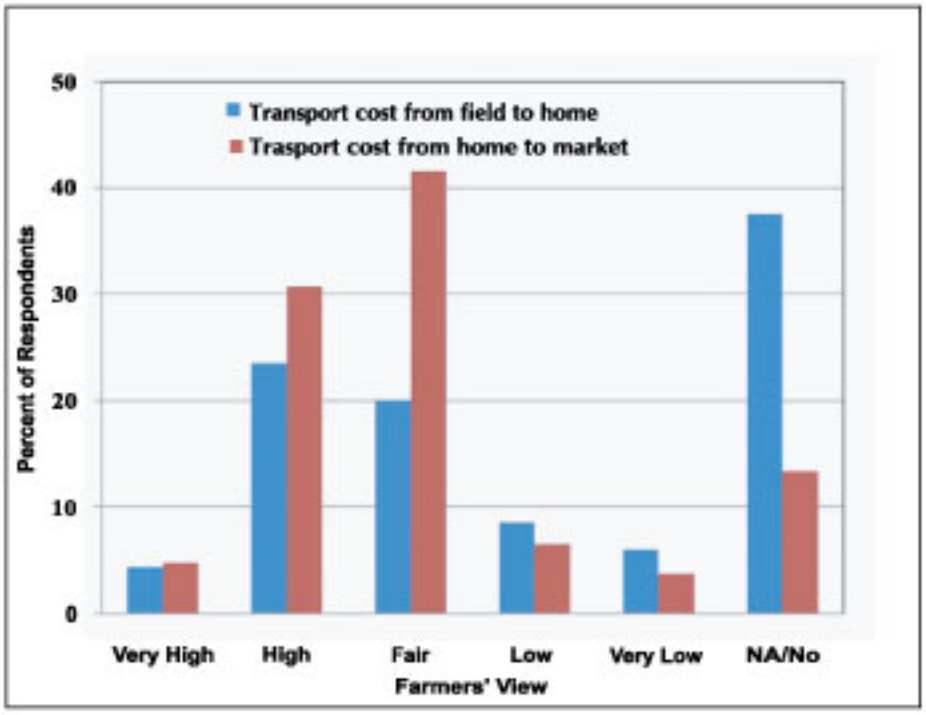


Figure 35. Transportation cost

Updated land type validation

Due to the lack of good road network, it was difficult to access all the selected spots for validation of the updated land type within the stipulated time. Nevertheless, in spite of several problems, the field team visited most of the spots and validated the updated land type of the upazila maps.

Ground truthing of the updated land type maps of different upazilas were found to be valid almost in all cases. Out of the 320 selected survey locations, there were a few deviations between the mapped and the real field situations. During validation it was found that the land types of most of the survey locations matched with the updated map produced by the software. However, some minor deviations were observed in few places.

Preparation of baseline report

After completion of the survey, a baseline report was prepared with a detail data analysis. The report covered detail description of the study areas, methodology of the survey, finding and outputs and survey database. Maps, charts, tables and field photos were also incorporated in the report.

Sharing the baseline report through workshop

A workshop on baseline survey report and draft version crop suitability assessment software was arranged on 21st September 2013 at 10:30 at the BARC conference room in Dhaka. Dr. Wais Kabir, Executive Chairman, BARC was present as Chief Guest while Engr. Md Waji Ullah, Executive Director of CEGIS was present as Special Guest in this workshop. The workshop was presided over by Md. Abeed Hossain Chowdhury, Director, Computer & GIS Unit, BARC where the officials from BARC and different organizations were present. Mr. Motaleb Hossain Sarker, Director, Ecology Division, CEGIS made a presentation of the baseline report and summarized the different development activities of GIS based Application Software. Mr. Shakil of CEGIS made a demonstration of the software for more than half an hour where he elaborated on different components, functionality and application of the software. The participants were then invited to make remarks on the software and to provide suggestions for improvement. Finally, it was decided that the valuable and acceptable recommendations from the workshop will be incorporated in the final version of the software.

Land Suitability Assessment for Major Cropping Pattern

Land use/crop suitability was determined through multi-factor analysis of different aspects of land/soil, climate and economic factors. The agro-edaphic and agro-climate suitability was determined separately based on the soil/land factors and climatic factors. Afterwards, land suitability for different crops was done through overlaying of agro-edaphic and agro-climatic suitability layers.

Thus crop suitability assessment framework was designed considering edaphic, agro-climate and economic parameters. This was done in consultation with the experts of the project and relevant officials of BARC. Based on suitability assessment framework, a desktop based suitability assessment tool has been developed using ArcGIS, Visual Basic (VB) and MS Access database. After designing the framework an user-friendly crop/land use suitability assessment model (CSAM) software was developed under GIS environment.

During the suitability assessment process suitability classification was considered that is described below:

Suitability classification: The suitability (Edaphic/Agro-climatic) assessment brings together all the bio-physical constraints and limitations likely to affect crops performance. The assessment takes account of all the inventoried attributes of the land (climate, inundation, soil, land form, etc.) relevant to the crop under consideration. To assess the land suitability, it is necessary to relate limitations to yields that may be anticipated if there are no further constraints for production from other factors. The maximum attainable yields for the five suitability classes are:

Very suitable (S1)	:	80% or more of maximum attainable yield (MAT)
Suitable (S2)	:	60 to 80% of MAT
Moderately suitable (S3)	:	40 to 60% of MAT
Marginally suitable (S4)	:	20 to 40% of MAT
Not suitable (NS)	:	Less than 20% of MAT

Development of Customized Crop Suitability Assessment Model

Overview of Tool

Considering the study requirements the GIS based CSAM tool was developed as a dynamic and user-friendly system under MS Windows operating system platform. The tool has been developed for automatic land type updating, assessment of crop suitability by using land factor limitation index, agro-climatic factors, benefit cost ratio and suitable cropping pattern. During the process of tool development, Visual Basic 6.0, .NET 2.0 have been used for developing the Graphical User Interface (GUI). Python script was used for backend geo-processing, Personal geodatabase was used for storing GIS files with associated attributes and MS Access for backend database. This tool was developed as a extension of ArcGIS 10.0. It is a type of extension that is automatically loaded and which is available in the customized toolbar menu in ArcMap document window. It is not dependent on any other extensions. The tool has a number of modules and sub-modules. Descriptions of the modules are as follows:

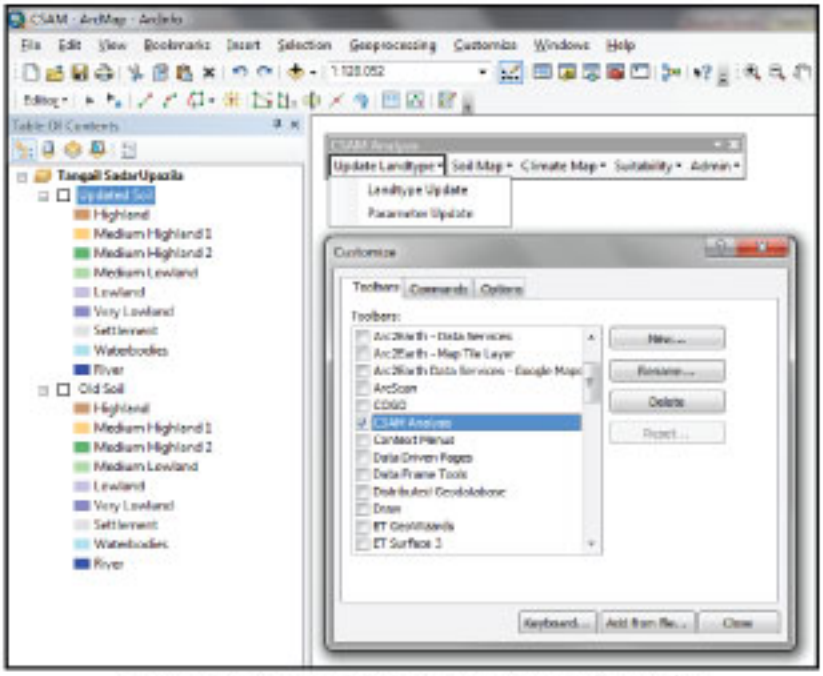


Figure 36 . CSAM Tool in the Customized toolbar dialog

System Requirement: The minimum system requirement includes supported platforms, hardware specification and pre-requisites of the software tools and technology is given in Table 29.

Table 29. System Requirement

Item	Description
Software	
Operating System	Microsoft Windows 7 Professional Edition or higher (32/64 bit)
GIS Tool	ArcGIS 10.0 (Build 2414)
Database (Back-end Tools)	MS Access 2007 or higher (32 bit)
Application framework	NET framework 2.0
Hardware	
Processor	Core 2 Duo or Higher
RAM	4 GB or Higher
Free Space (Hard Disk)	10 GB (Only for 6 upazila)

Land type updating module: The Land type updating module was developed based on elevation point and soil unit map. The elevation data has been used to differentiate the land types within the map unit boundary. The module is used for generating a dynamic land type updated boundary using some predefined process, techniques and percentage of land types within a map unit boundary provided by Upazila Nirdeshika. This module was developed using Visual Basic, Asp.Net(C#), python and ArcGIS Desktop. The core development technique includes the spot height value and soil unit map as an inputs. Therefore, elevation break points of each land type within a mapping unit are calculated considering elevation of map unit and area percentage values under different land type as per Upazila Nirdeshika. Then, the new land type was defined by using elevation break points.

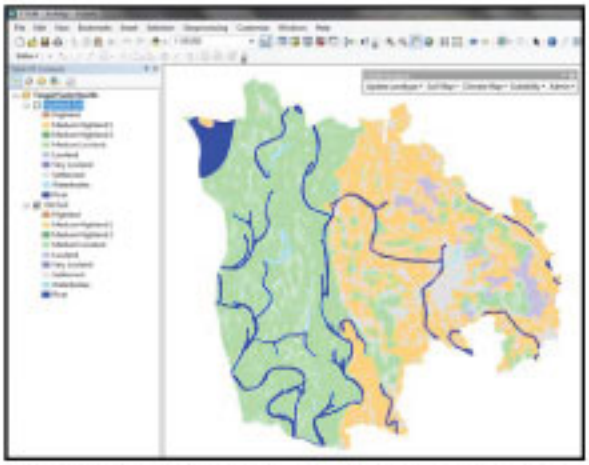


Figure 37. Existing land type of Tangail Sadar upazila

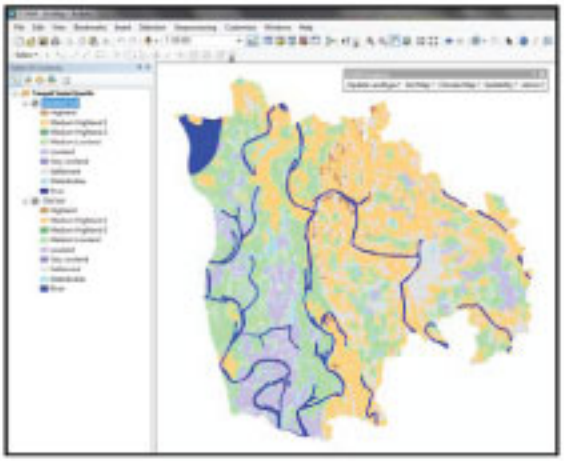


Figure 38. Updated landtype of Tangail sadar upazila

Soil and climate information updating module: The soil and climate information updating module establishes linkage among the updated land types and soil information. The following are the soil parameters: land type, relief, water recession, drainage, soil texture, soil consistency available moisture holding capacity, soil reaction and soil salinity. In case of climate information, the following are the parameters: Pre-kharif transition period, Kharif growing period, Rabi growing period and Extreme summer temperature zones. The module has dynamic facility to link soil and climate parameters with updated land type shape file (ArcGIS spatial data file).

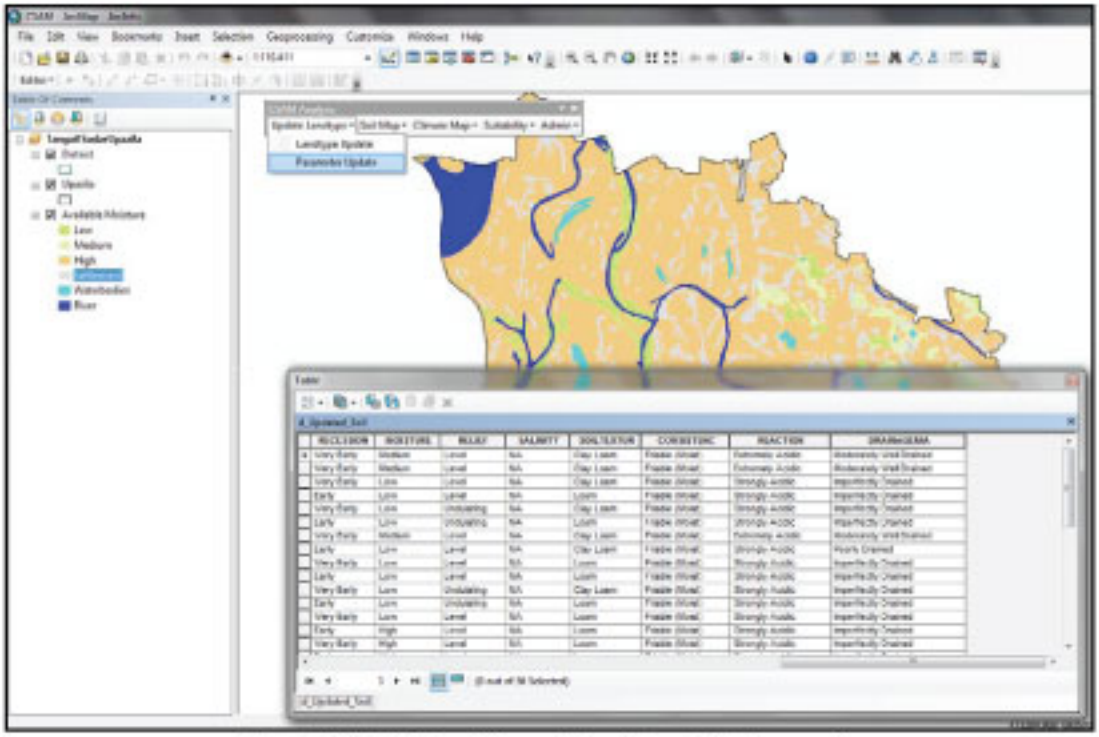


Figure 39. Soil information update of Tangail Sadar upazila

Soil Map

This module was developed by combining different soil parameters. It has a user friendly interface to create maps of different soil parameters. Soil mapping is displayed in ArcGIS document window by selecting soil parameter and upazila and produce thematic maps.

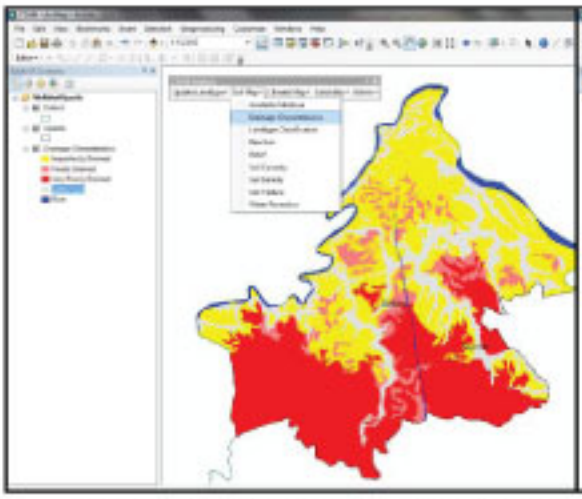


Figure 40. Drainage map of Mollahat upazila

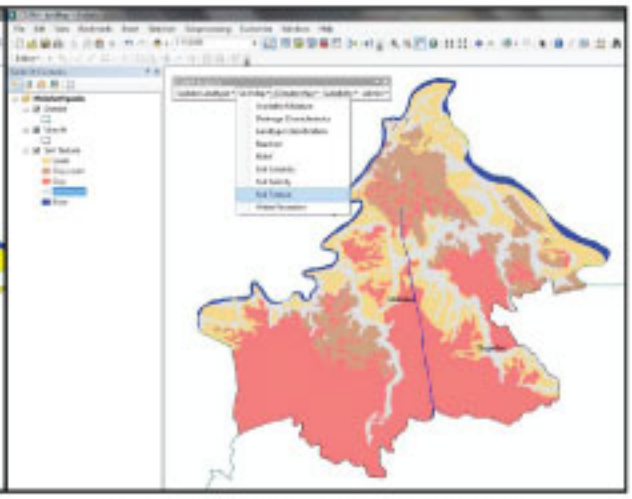


Figure 41. Soil texture of Mollahat upazila

Climate Map

This module was developed based on following agro-climatic parameters: Kharif Growing Period, Pre-kharif transition period, Thermal zones, Extreme summer Temperature zones. This tool has facility to display maps of agro-climatic parameters for the selected upazila.

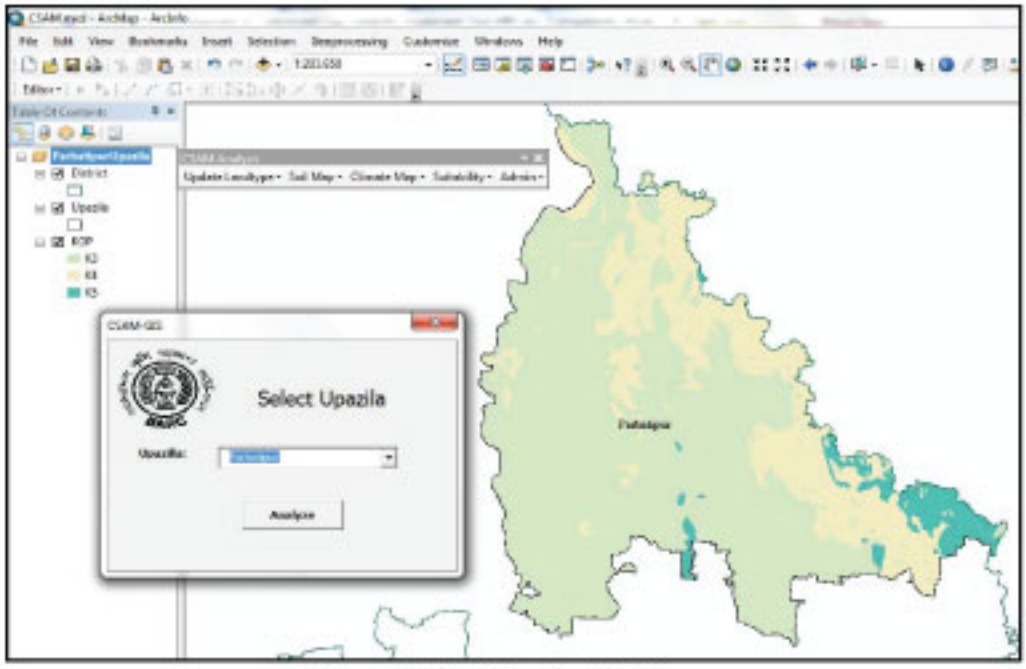


Figure 42. Kharif Growing Period map

Suitability

Edaphic Crop Suitability

Based on the major physical properties of land and soil i.e., land type, relief, water recession, drainage, soil texture, soil consistency available moisture holding capacity, soil reaction and soil salinity the Edaphic suitability module was developed. This module is capable of automatically generating crop specific suitability by considering the degree of physical factors limitations for the crop. The Microsoft Access database is used in backend to establish linkage between crop list, physical factors limitation, scale of five suitability classes and attribute of the updated land type polygons. The module can link crop suitability class with updated land type shape file. Thematic crop suitability mapping can be displayed in ArcGIS document window by selecting the crop and upazila.

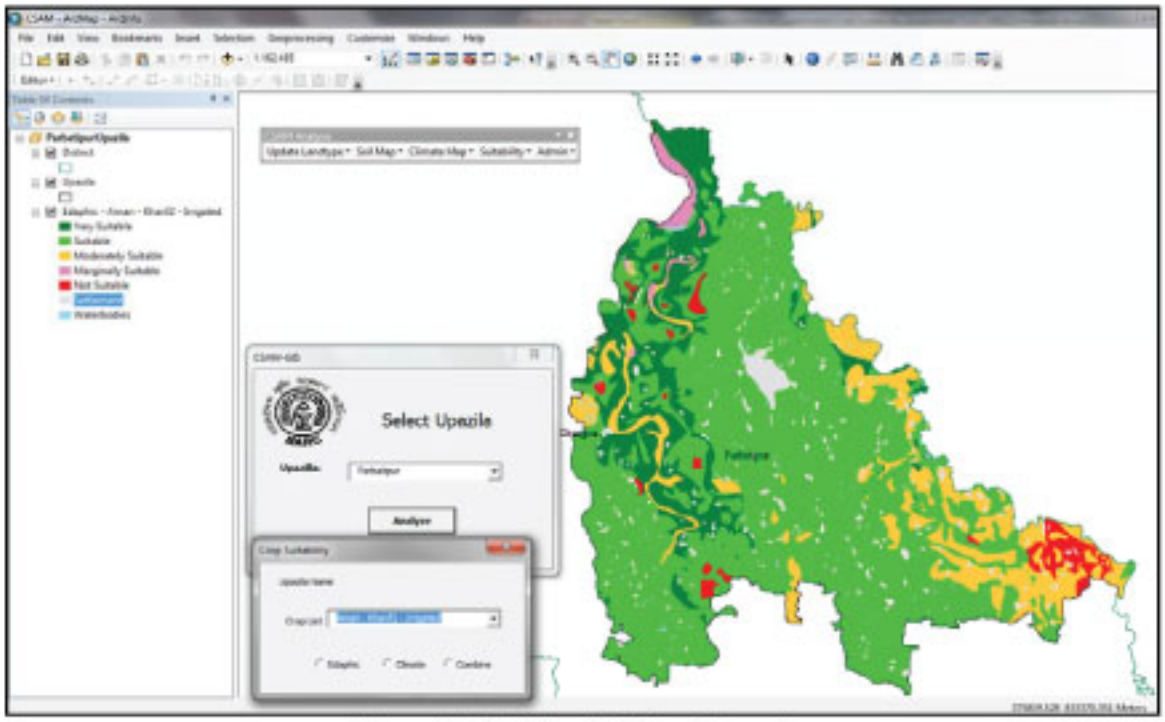


Figure 43. Edaphic suitability of Aman rice

Agro-Climatic Crop Suitability

This module is responsible for generating agro-climatic crop suitability by considering degree of climatic factors limitations, such as length of kharif growing period, pre-kharif transition period, thermal zone and extreme temperature limitations of each crop. Similar approach was followed for this module as used for edaphic crop suitability.

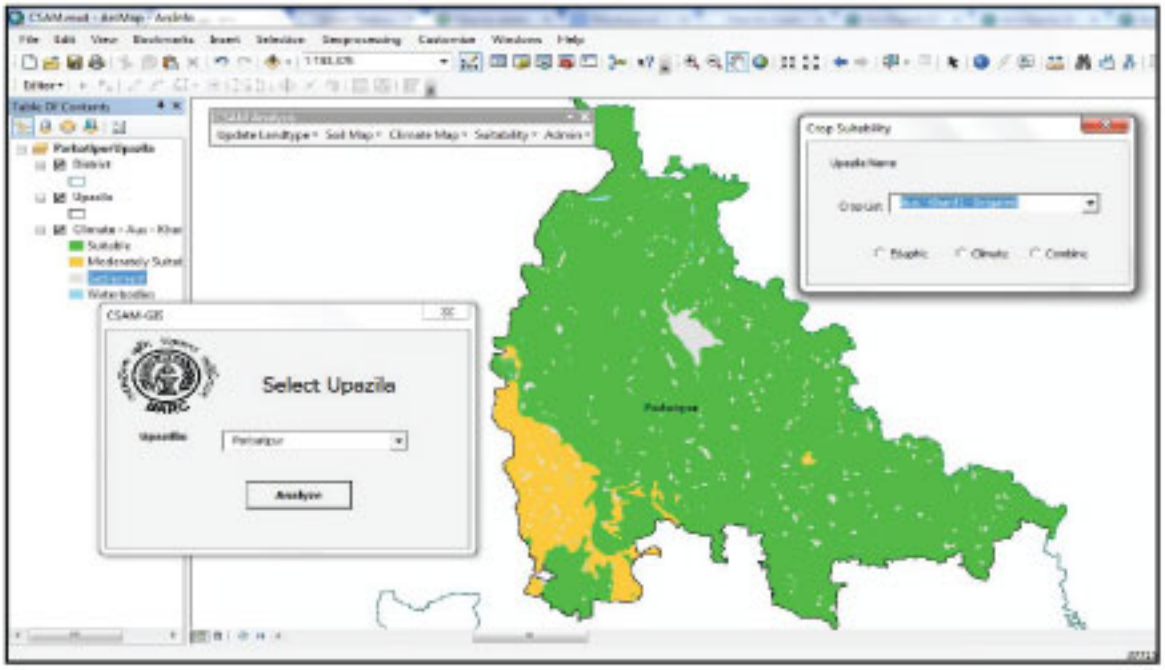


Figure 44. Climatic suitability of Aus rice

Combined Crop Suitability

This module performs combined suitability analysis of specific crop based on agro-edaphic and agro-climatic parameters. This tool considers limitation factors of both land and climatic parameters. Land factors are more limiting than the agro-climatic factors. Agro-climatically, most parts of Bangladesh fall under suitable to moderately suitable categories for the selected crops. It has facility to generate suitability maps by selecting crop and upazila. Maps can be produced for delineating potentially suitable areas for 15 different crops.

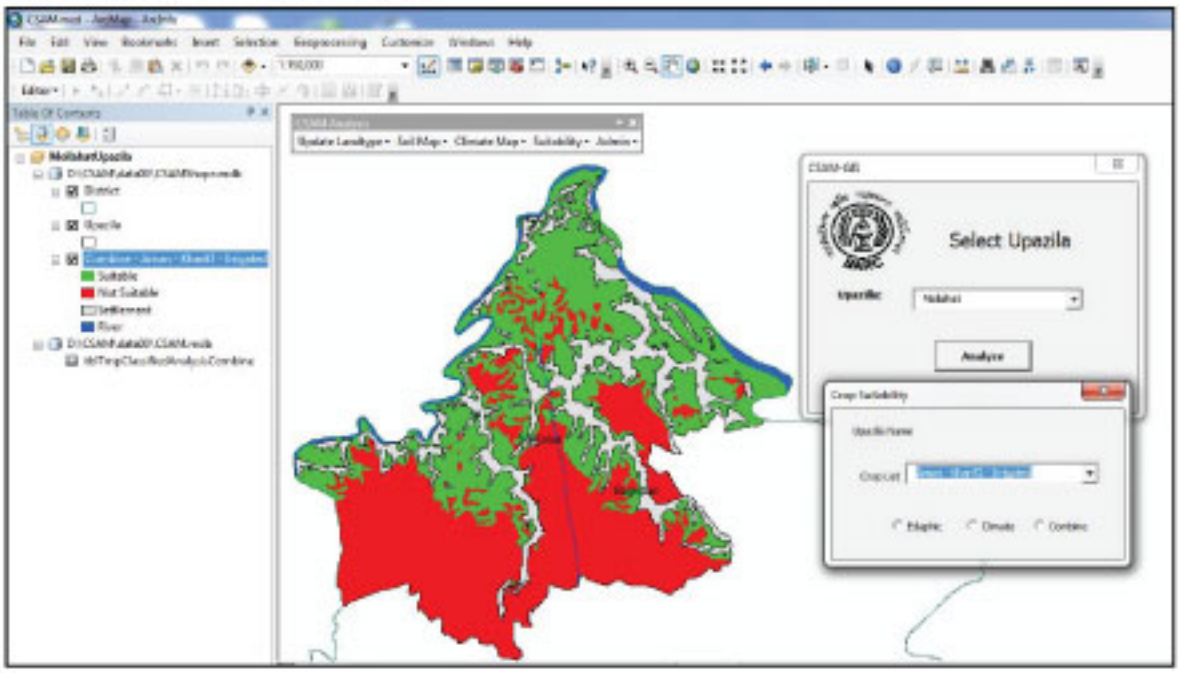


Figure 45. Edaphic suitability of Aman crop

Benefit Cost Ratio Module

The module was developed to analyse economic return of major crops. This module considers production of crops, cost of production and market price of crops to calculate net economic return. The Microsoft Access database is used to establish linkage between crop list, market price, total production and per unit production cost. The tool can calculate benefit cost ratio for the selected crop in two different options i.e., benefit cost ratio including all cost and benefit cost ratio on the basis of only cash cost.

Cropping Pattern Analysis Module

The module performs analysis for combining suitable crops that can be grown in a cropping year. An application named "**Cropping Pattern Viewer**" was created to provide a GIS-based interface to this database. It enables the user to view the spatial distribution of each cropping pattern with its suitability status within a updated soil units or for the entire area of upazila (Figure 46-48).

The Microsoft Access database was used for generating all possible cropping pattern in a mapping unit and to assess suitability of each cropping pattern based selected criteria. Thematic cropping pattern map can be displayed in ArcGIS document window by selecting upazila.

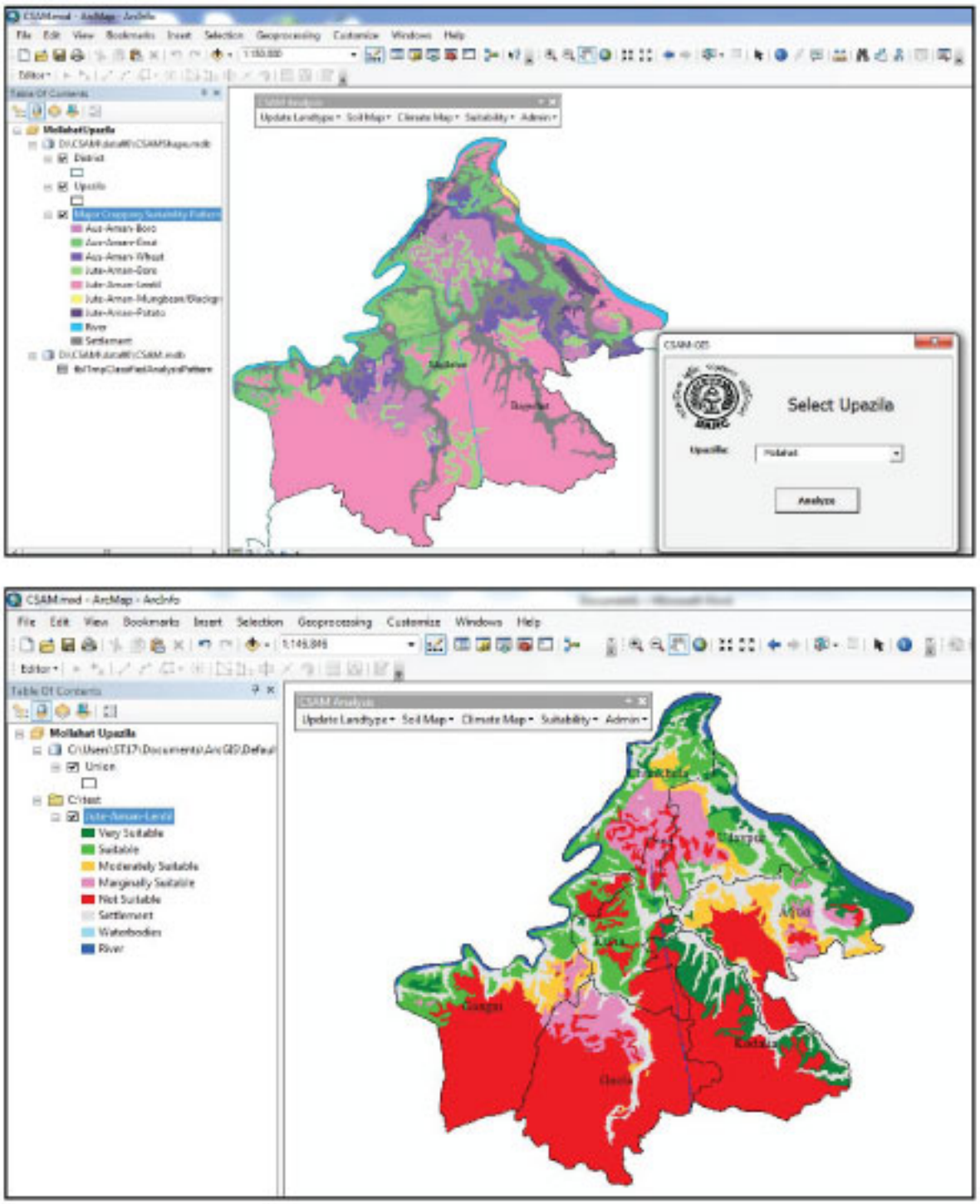


Figure 46. Spatial distribution of specific cropping pattern with suitability status of Mollahat upazila

An application named **"Economically Best Suitable Cropping Pattern Viewer"** was developed to provide a GIS-based interface that allows the user to view the spatial distribution of economically best suitable cropping patterns by updated soil units or for the entire upazila.

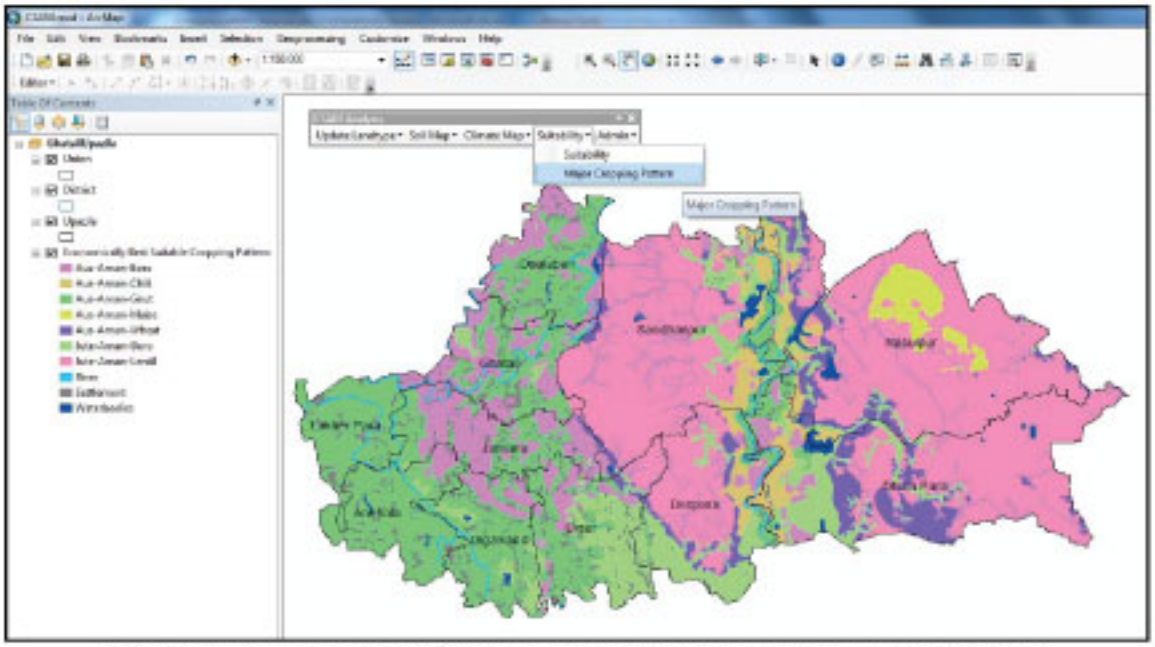


Figure 47. Economically best suitable cropping pattern of Gatail upazila in Tangail district

Economically best suitable cropping pattern map is intersected by union (lowest administrative unit) layer and summarized by cropping patterns and by unions that allows the user to view the tabular format of economically best suitable cropping pattern by percentage within union level. The economically best suitable cropping pattern by percentage within union level was presented in Table 30.

Table 30. Economically best suitable cropping pattern by unions of Tangail Sadar upazila

Economically best suitable cropping pattern	% of Area coverage												
	Baghil	Danya	Gala	Gharinda	Hugra	Kakua	Karatia	Katuli	Magra	Porabari	Pourasabha	Silimpur	Upazila
Aus-Aman-Chili	0.3	1.2	0.0	0.0	14.8	1.5	0.0	5.8	2.0	8.6	0.0	6.2	4.2
Aus-Aman-Gnut	0.4	0.0	18.9	27.7	0.0	0.0	35.3	0.0	0.1	0.0	2.0	0.3	5.4
Aus-Aman-Wheat	6.9	2.1	0.0	0.0	6.2	1.5	0.0	3.6	2.2	3.3	0.0	0.4	2.5
Jute-Aman-Boro	0.0	0.9	6.9	14.6	0.0	0.0	16.4	0.0	0.1	2.0	6.6	1.1	3.0
Jute-Aman-Gram	2.3	18.8	0.2	0.0	0.0	0.0	2.0	0.0	1.2	13.3	19.9	19.8	4.9
Jute-Aman-Lentil	90.1	77.0	74.0	57.6	78.9	97.1	46.2	90.7	94.5	72.7	71.5	72.1	80.0
Total	100	100	100	100	100	100	100	100	100	100	100	100	100

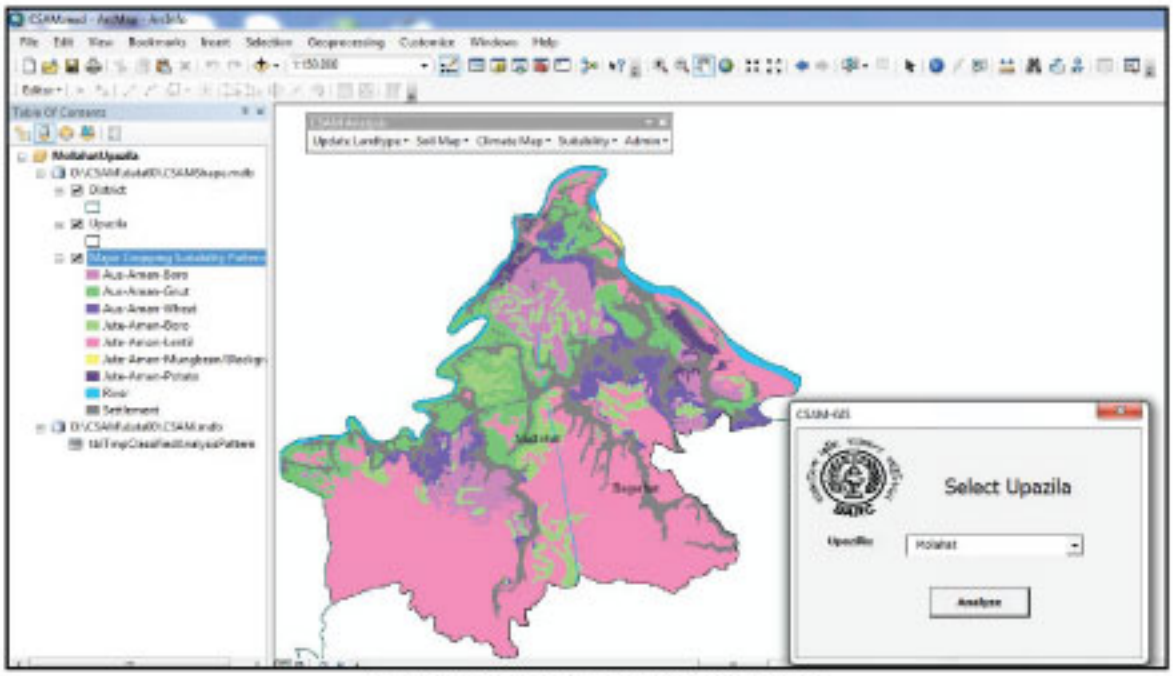


Figure 48. cropping pattern suitability map

Field validation of the developed model outputs

After generating the outputs (maps and table) from this GIS based CSAM tool, the validation of the maps have been carried out in the fields. Field level consultation meeting and focus group discussion have been organized to validate the maps as well as the accuracy/performance of the tool including physical visit at the farmer's plots. Since all the suitability assessments were done for the potential suitability, it is likely to deviate from reality. In other words, the modeled outputs may differ from reality although there is potentiality for growing a certain crop or a cropping pattern; the farmers may not be interested because of his personal preference for the crop or for some other reasons. The major reasons could be lack of demand, marketing, benefit, etc. or simply because they have not tried that crops or croping patterns before (Appendix Figures 10-20).

10. Research Highlights:

- A comprehensive crop suitability assessment framework has been developed which includes different important processes and analyses of land/soil, agro-climate and benefit cost ratio of major crops and cropping patterns of Bangladesh.
- A land type updating tool has been developed under this study and the users will be able to generate updated land type maps using updated DEM. Upazila Nirdeshika map do not show different land types within a map unit but this tool enables the user to delineate the land types within a map unit.
- Databases on agricultural and socio-economic condition of 320 farmers in eleven selected upazilas have been generated through baseline survey.
- Databases on land and soil, climatic parameters, and benefit cost ratio for 15 crops have been created.
- A user-friendly Crop Suitability Assessment Model (CSAM) has been developed where the user will be able to change the parameters and set the options for crop suitability assessment. Due to its flexibility, the users will be able to generate crop suitability maps under different options or field conditions.

- Algorithm and rules for identifying economically best suitable cropping pattern have been developed by using benefit cost (B/C) ratio and combined suitability rating of individual crop.

11. Major Attainments (in relation to the set objectives) :

a. Technical : Output, Outcome and Impact

Sl. No	Major technical activities performed in respect of the set objectives	Output(i.e. product obtained, visible, measurable)	Outcome(short term effect of the research)	Impact(long term effect of the research)	Remarks(reason, if anything otherwise plus any other)
1.	Baseline survey of the study areas	Agricultural and socio-economic condition of 320 farmers in eleven selected upazilas generated	Data/information used for socio-economic analyses	Change in livelihood of the target group	-
2.	Development of Databases	Databases on land and soil, climatic parameters, and benefit cost for 15 crops created	Data/information used for land suitability assessment	The databases can be accessed to identify change over time	-
3.	Land type updating	Methodology for delineation land types within a mapping unit developed	Land types within a mapping units of upazila Nirdeshika maps delineated	More realistic land use planning would be possible	-
4.	Development of GIS based tools (software) for land suitability assessment	Land suitability for growing 15 major crops and cropping patterns can be assessed using the GIS based tools	More precise land suitability assessment with spatial delineation	Better crop production options would be available for higher economic return	-
5.	Manpower development	25 NARS scientists and extensionists were trained	Train other persons of NARS and DAE	Trained manpower on land use planning would be available	-

b. Procurement

Sl. No	Approved provisions of Procurement *(list major items)*	Achievement	% of achievement	Remarks (statement on the handing over of the materials procured/developed as per LoA plus any other)
1.	Service of CEGIS	Completed	100	CSAM Software and other equipment will be handed over to Computer and GIS Unit, BARC
2.	Furniture	Completed	100	
3.	IPS	Completed	100	
4.	LCD-TV, Digital Camera, DVD Player	Completed	100	

5.	Computer, Accessories & Software	Completed	100	-
6.	Photocopier, Fax machine	Completed	50	Permission not given for procurement of fax machine

c. HRD/ Training

Title (e.gPh.D/MS/ Trainings, workshops conducted etc.)	Target	Attainments	No. of participants	Benefit of the higher studies/trainings(application of the learning, productivity enhancement	Remarks (reason, if anything otherwise)
Inception workshop	1	1	50	-	-
Mid-term workshop	1	1	60	-	-
Training on CSAM software	2	2	40	Help to use the Software as landuse Planning tool	-

d. Financial

Sl. No	Major Head	Fund received (Tk.)	Expenditure (Tk.)	Balance/Unspent (Tk)	Remarks (reason, if anything otherwise)
1.	Salary and Remuneration	384,050	384,050	-	-
2.	Research Expenses	5,180,294	5,180,294	-	-
3.	Operating Expenses	890,000	890,000	-	-
4.	Fuel Oil and Maintenance	385,000	385,000	-	-
5.	Workshop/ Seminar etc.	289,738	289,738	-	-
6.	Publication and Printing	210,000	210,000	-	-
7.	Contingencies	251,586	251,586	-	-
8.	Capital Expenses	3,962,682	39,62,682	-	-

e. Materials developed/Publications made:

Type of material/publication	Title	Number	Remarks(being used by/meant for/any other)
Technology development	-	-	-
Process development	Land suitability assessment software	1	-
Information development	-	-	-
Journal publication	-	-	-
Books/Monographs/Manual published			
Booklet/leaflet/flyer etc. published	Leaflet	1000	Project description
Any other (patenting of technology etc.)	Project completion report	150	-

12. Sub-project Auditing (cover all types of audit performed)

Types of Audit (e.g. BARC/Implementing agency/FAPAD/World Bank/others)	**Major observations/issues/objections raised, if any**	**Status at the sub-project end**	**Remarks**
World Bank	None	**No audit objection raised**	-
FAPAD	None		-

13. Reporting

Report type	**Actual date of submission(s)**	**Total Number(s)**	**Remarks (if anything otherwise)**
a. Inception report	11-05-2011	1 (One)	-
b. Annual reports July 2011 to June 2012	20-03-2013	1 (One)	-
c. Statement of expdts.(SoE)			-
- August 2011 to December 2012	-		
- January to September 2013	07-10-2013		
- October to December 2013	16-02-2014		
- January to May 2014	08-06-2014		
- June 2014	15-07-2014		
- July to November 2014	30-11-2014		
- Final statement of Expenditure	30-11-2014		
d. Quarterly report(s)			-
e. Six monthly report			-
- July to December 2012	20-03-2013	2 (two)	
- January to June 2013	17-11-2013		
- July to December 2013	24-05-2011	2 (two)	
- January to June 2014	16-07-2012		
f. Procurement plan			
g. Annual research program format	-		-
h. Environmental monitoring (Annual Basis)	-		-
i. Social safeguard status (Before and at the end)	-		-
j. Field Monitoring Report(s)	-		-

14. Problems/Constraints (bullet points- max. 5 nos.) :

- The project activity at the initial stage got delayed due of lengthy procedure of procurement and handling the matter in:
  - Hiring of firm for baseline survey of the study areas and development of GIS based tools (software) for land suitability assessment which were major activities of the project
  - Procurement of computer and related accessories

15. Suggestion for future:

The outputs of the land suitability assessment of major cropping pattern of the study areas is produced in GIS map form as well as in tabular format. It is anticipated that, the software will facilitate carrying out detail level agricultural production planning in Bangladesh. Keeping in view the potentiality of the software this effort was undertaken as a pilot study, so that the methodology developed in this study could be replicated for the remaining upazilas of the country. It is expected that, the findings of the study will benefit the agricultural scientists, extensionists, planners, decision makers and farmers for optimizing the utilization of land resources thereby increasing the agricultural production and maximizing the benefits keeping the productivity of land at sustainable level. At national level, the self-sufficiency in food grain production will be sustained through the increase of land productivity. However, the farmers will be the ultimate beneficiaries from the findings of the project.

For sustainable deployment of CSAM, intensive validation programme could be taken up in 30 Agro-ecological zones (AEZs). The tool could be further improved based on countrywide field validation results and user response. After validating and successful implementation of CSAM in 30 AEZs, the model can be deployed and replicated at different upazila agriculture offices in the country. Intensive capacity building programme and deployment of the CSAM can be initiated by BARC. Local level deployment of the crop suitability assessment tool will reduce production cost and substantially contribute in farm productivity enhancement.

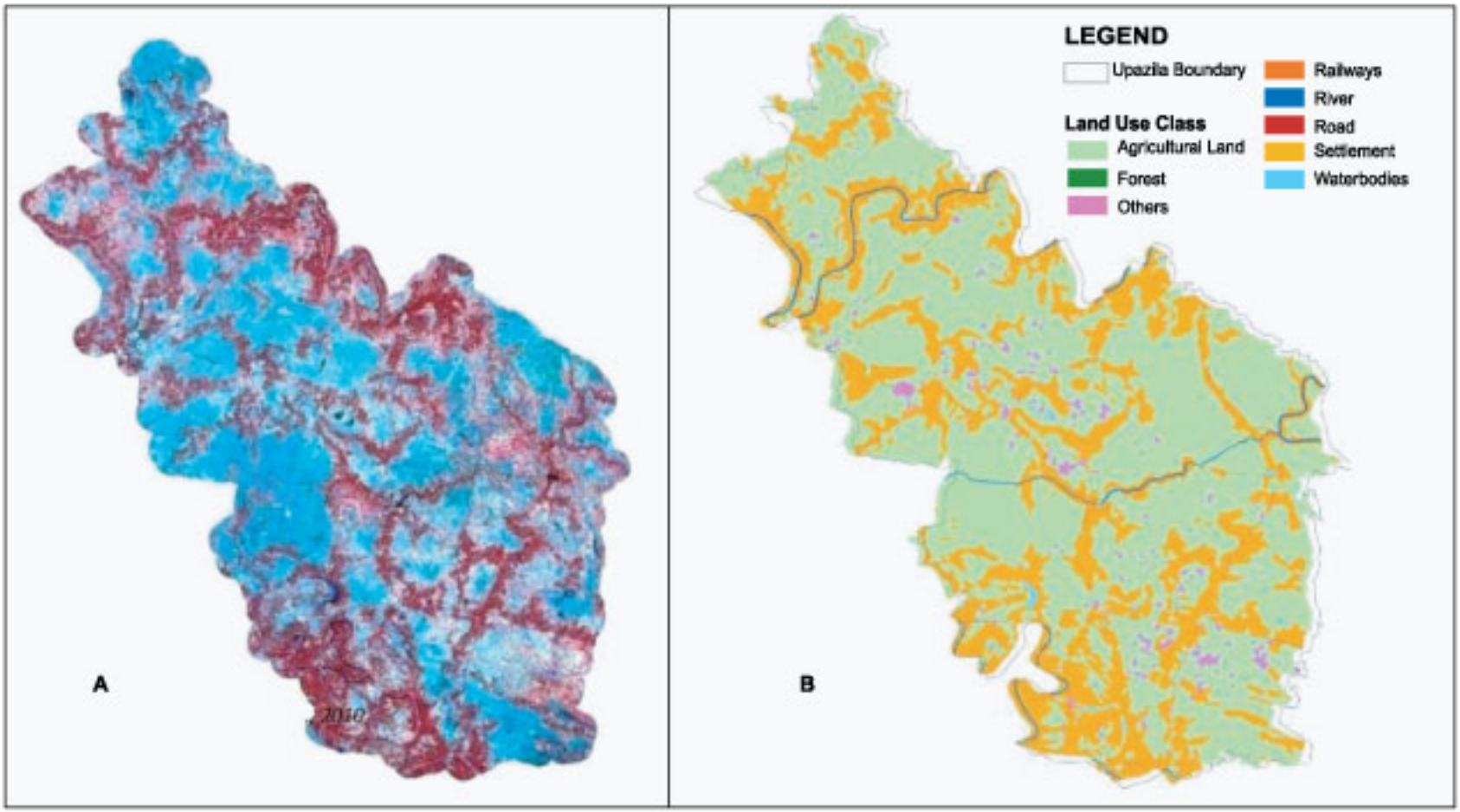
(Md. **Abeed Hossain Chowdhury**)
Principal Investigator
Date : 30-11-2014

Member Director (P&E), BARC
Counter signature of the Head of the agency/authorized representative
Date : 30-11-2014

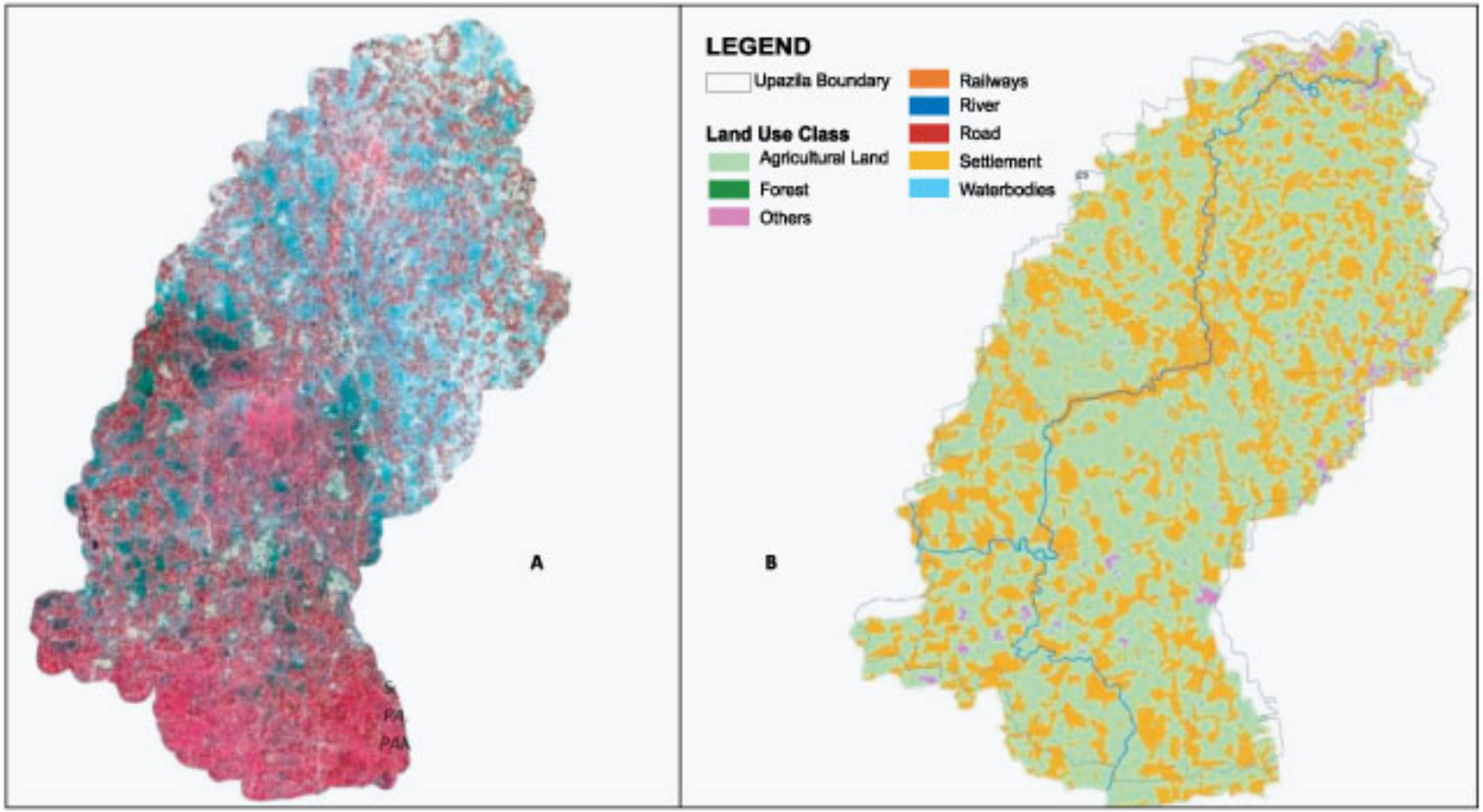
Environmental Screening Matrix: Agricultural Research under SPGR

Sl. No.	Environmental issue	Component	Improvement/Deterioration (Before)				Improvement/Deterioration (After)				Remarks
			Small	Moderate	Large	None	Small	Moderate	Large	None	
1.	*Biodiversity*	Flora				√				√	
		Fauna				√				√	
		Genetic diversity				√				√	
		Exotic varieties				√				√	
		Local varieties/ cultivars				√				√	
		Hybrids				√				√	
2.	*Soil quality*	Organic matter				√				√	
		Chemical fertilizer use				√				√	
		Soil salinity				√				√	
		Fertility status				√				√	
		Microbial activity				√				√	
		Heavy metal contamination				√				√	
		Water quality				√				√	
3.	*Agro-Chemicals*	Pesticide use				√				√	
		POPs				√				√	
		IPM				√				√	
		Pest infestation				√				√	
		Bio-pesticides				√				√	
		Health hazard				√				√	
4.	*Pollution*	Soil				√				√	
		Water				√				√	
		Air				√				√	

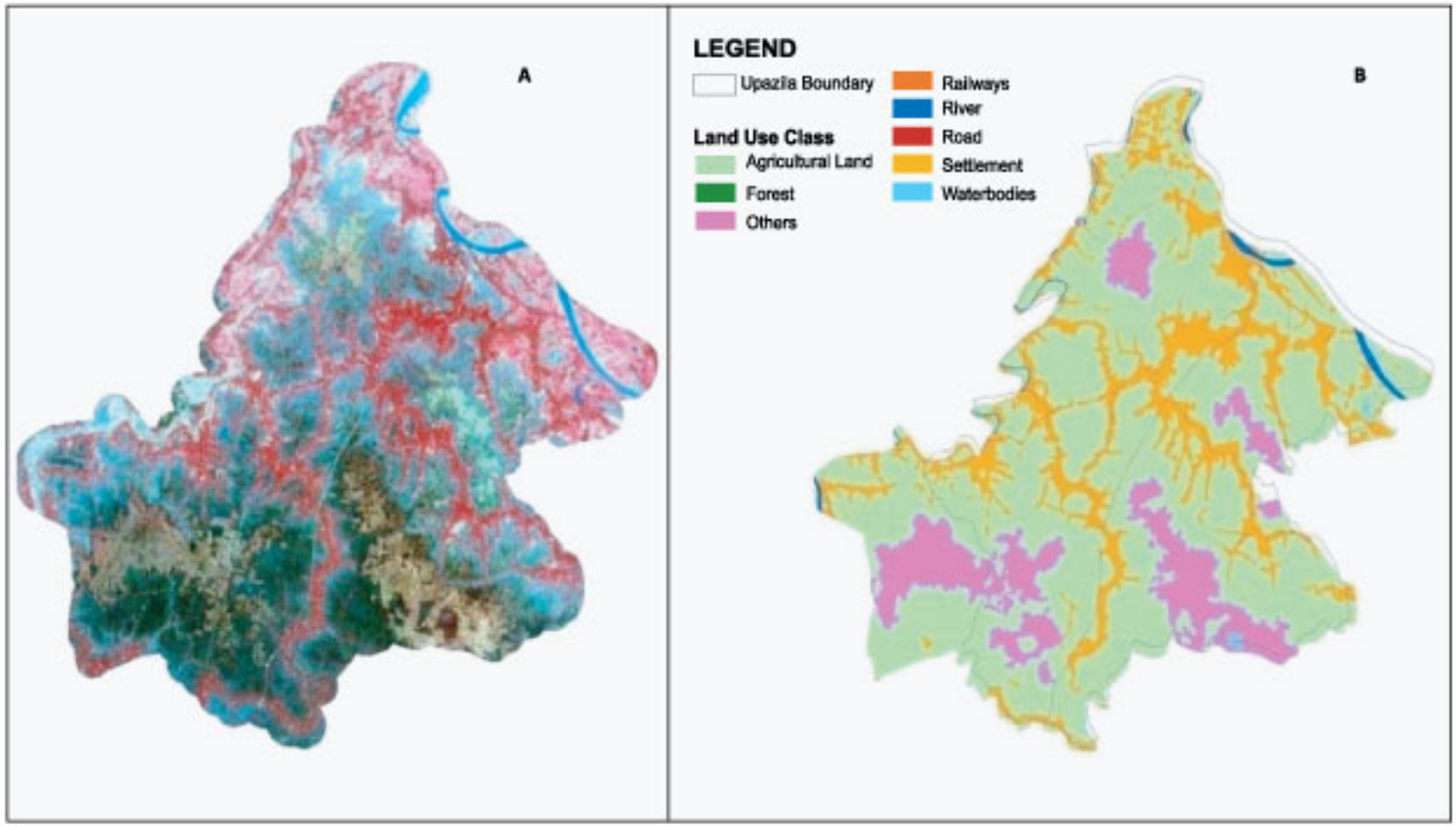
Appendix 1



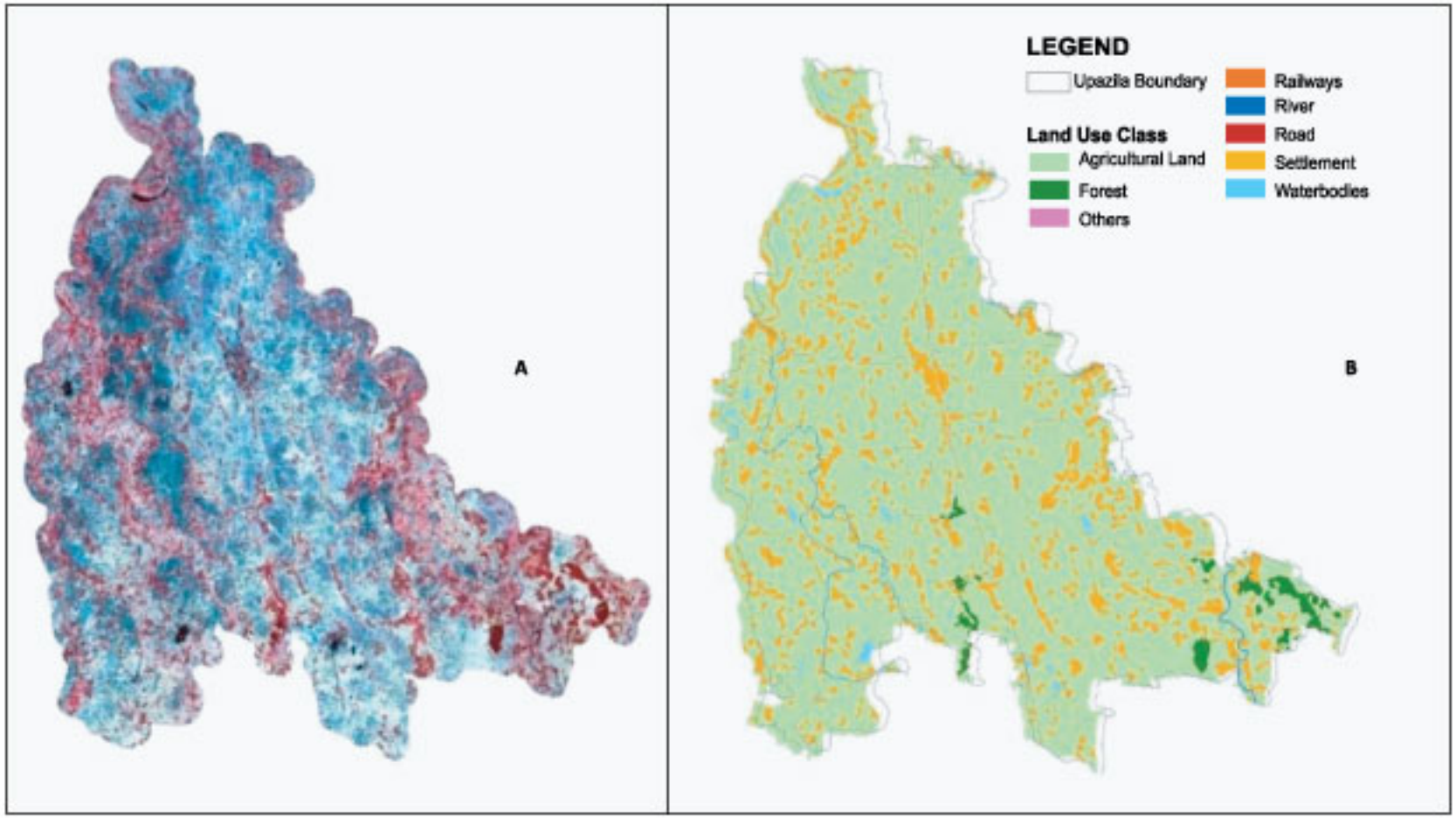
Appendix Figure 1. Satellite Image (A) and Landuse Map (B) of Bagher Para Upazila



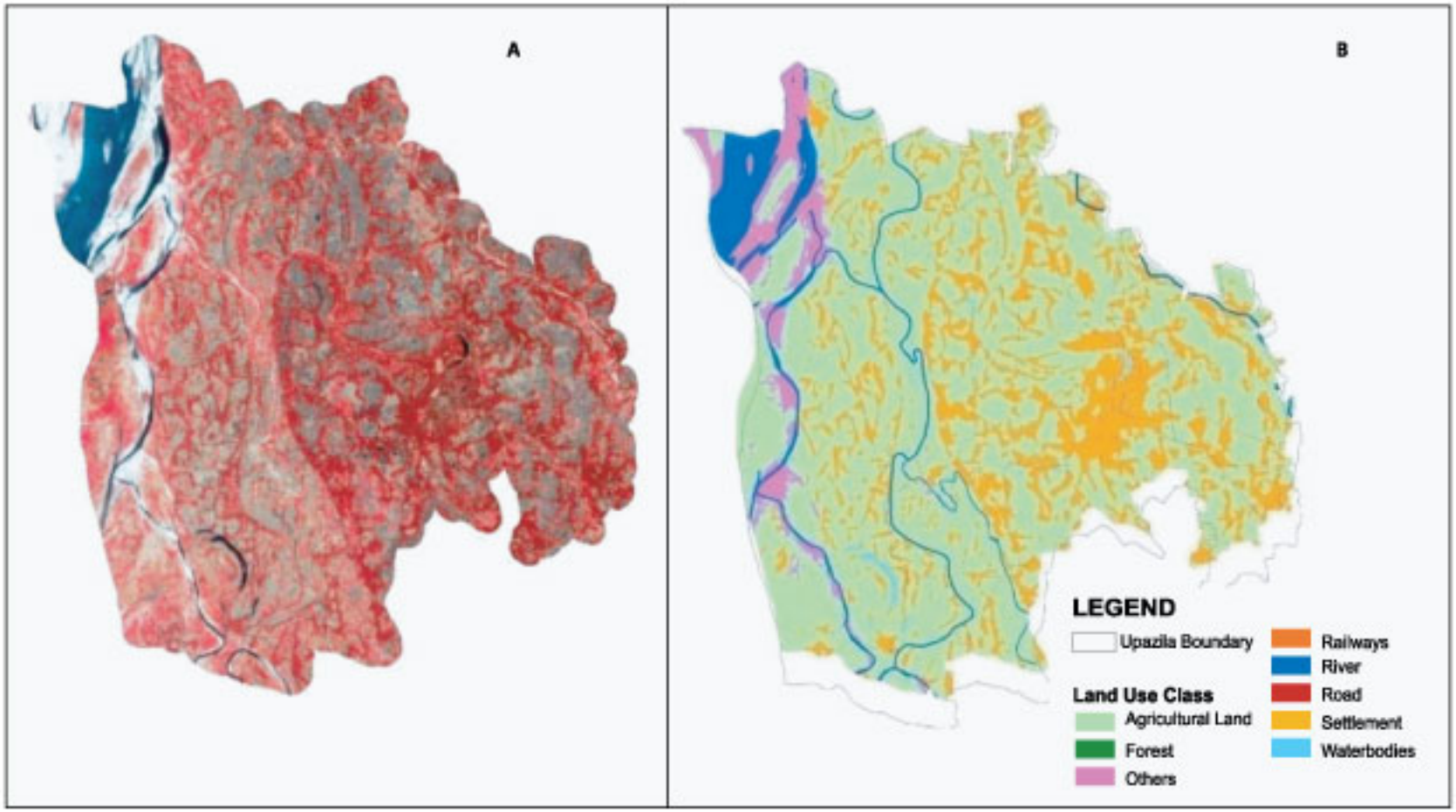
Appendix Figure 2. Satellite Image (A) and Landuse Map (B) of Laksam Upazila



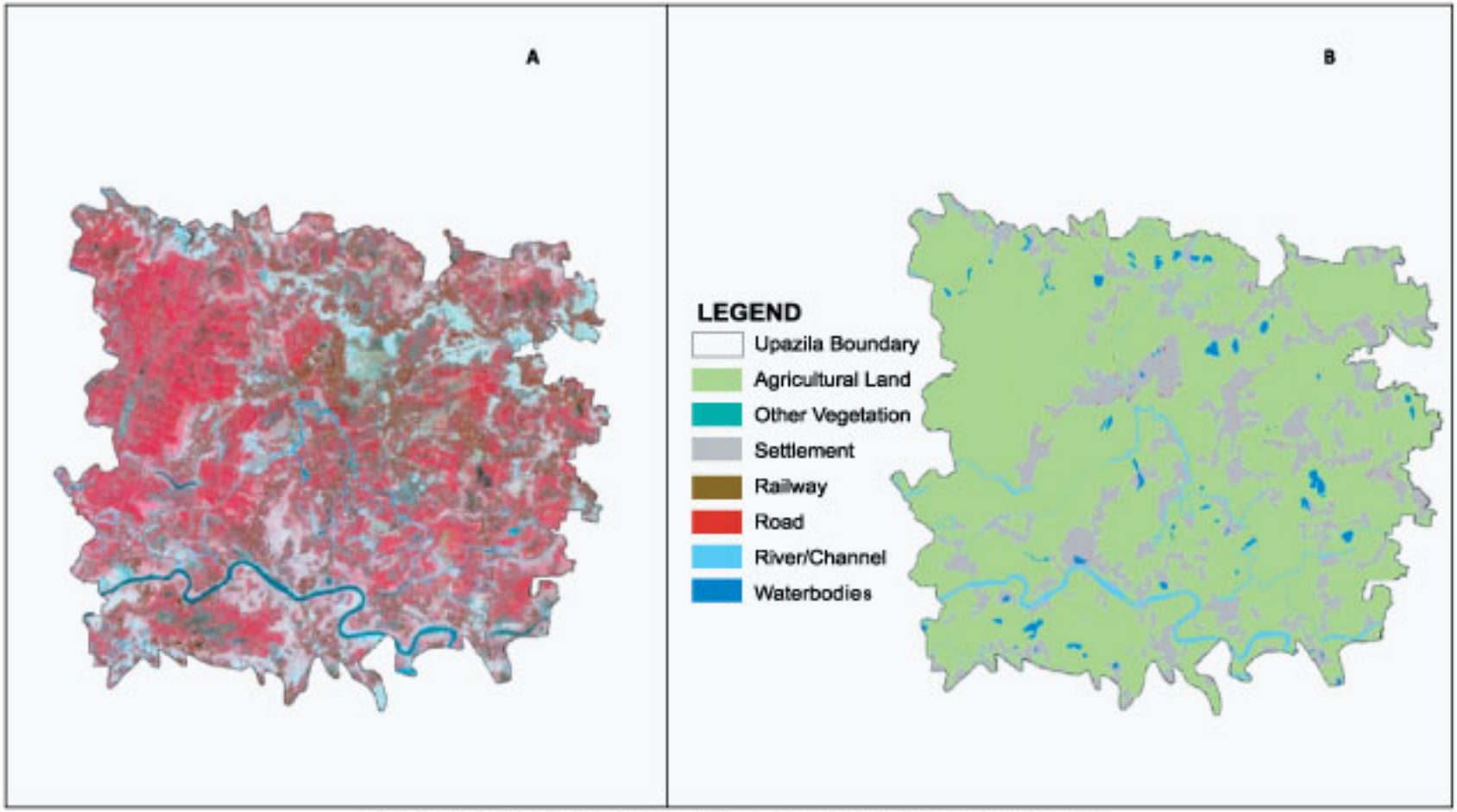
Appendix Figure 3. Satellite Image (A) and Landuse Map (B) of Mollahat Upazila



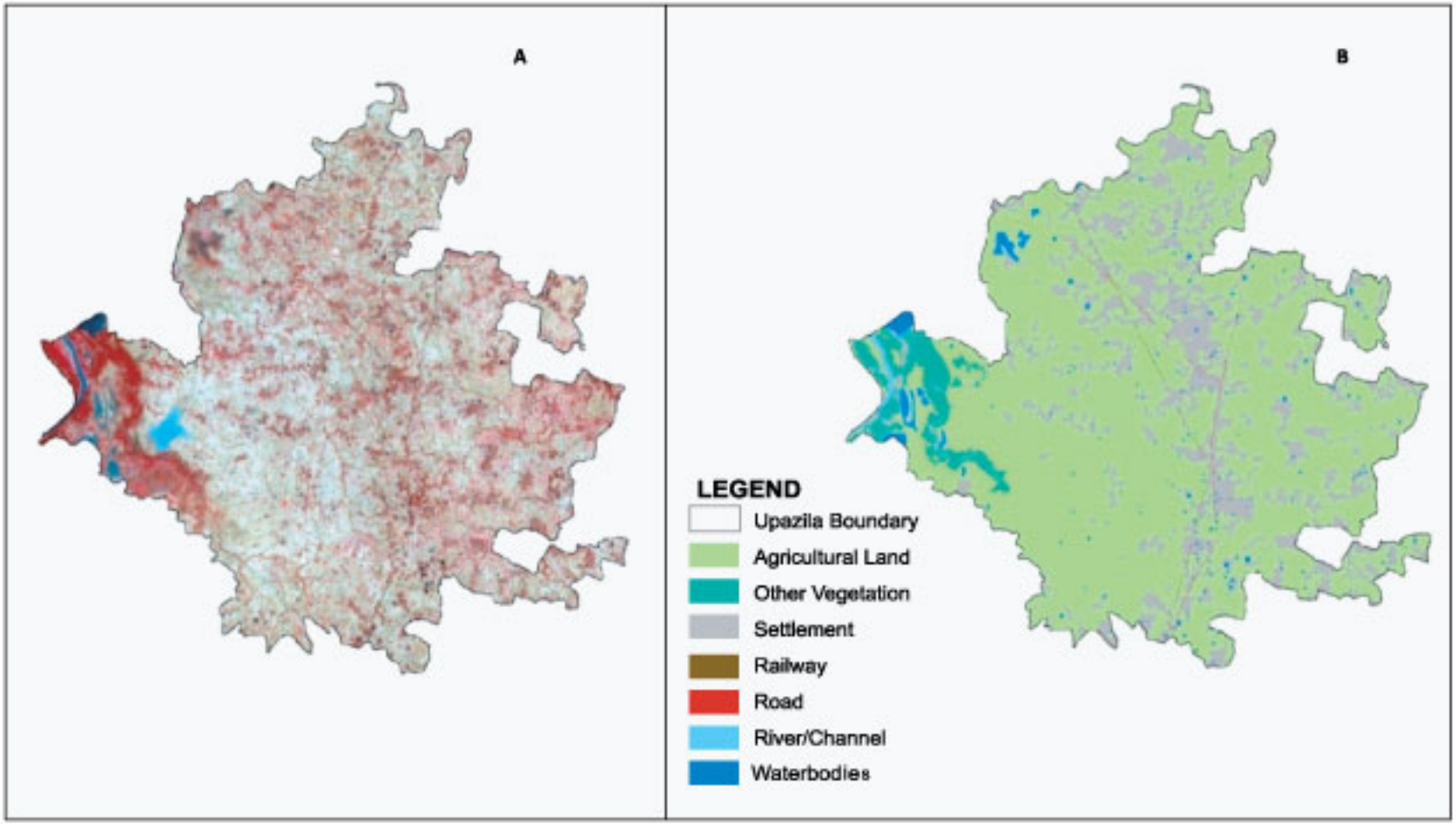
Appendix Figure 4. Satellite Image (A) and Landuse Map (B) of Parbatipur Upazila



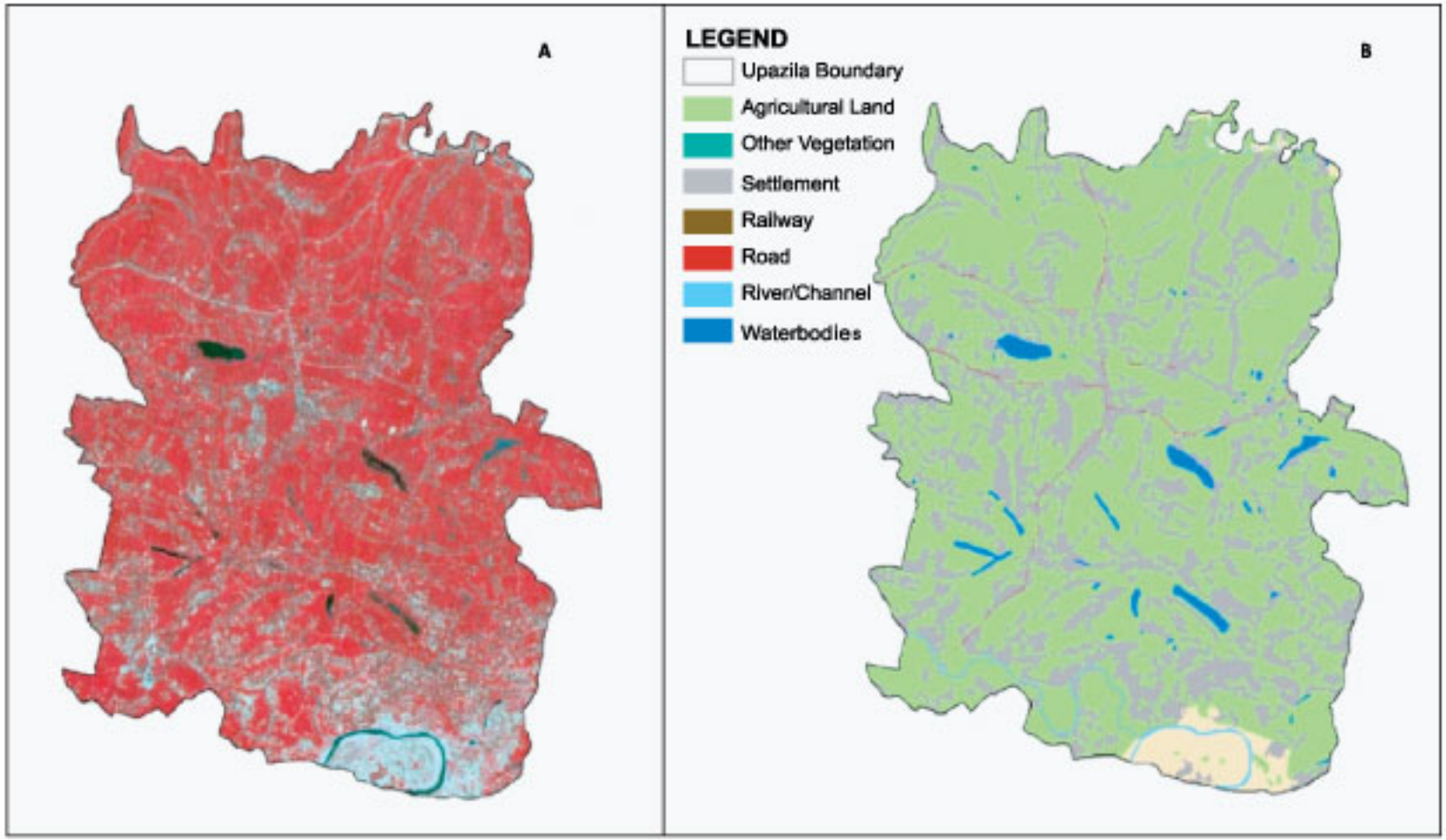
Appendix Figure 5. Satellite Image (A) and Landuse Map (B) of Tangail Sadar Upazila



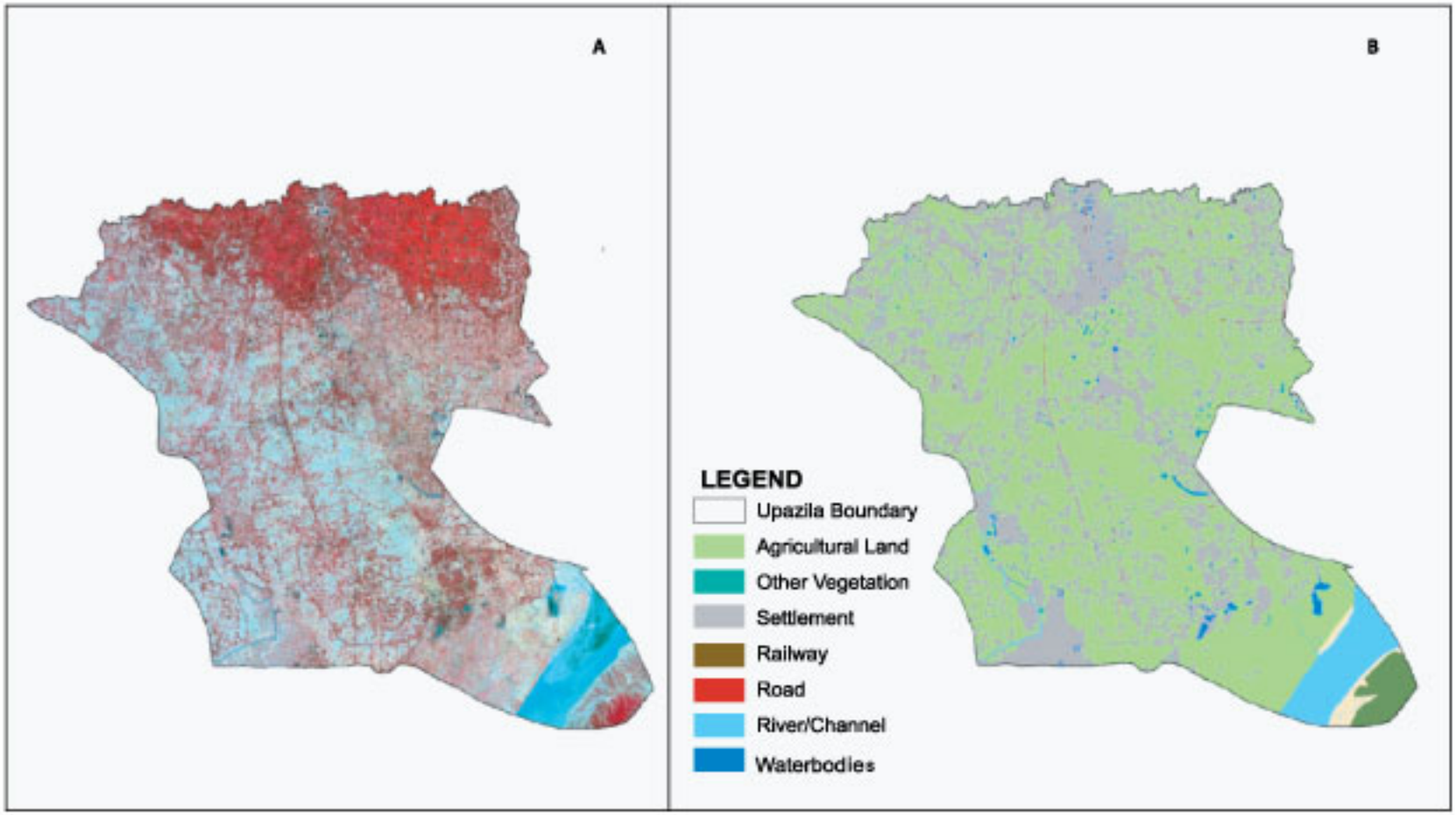
Appendix Figure 6. Satellite Image (A) and Landuse Map (B) of Jagannathpur Upazila



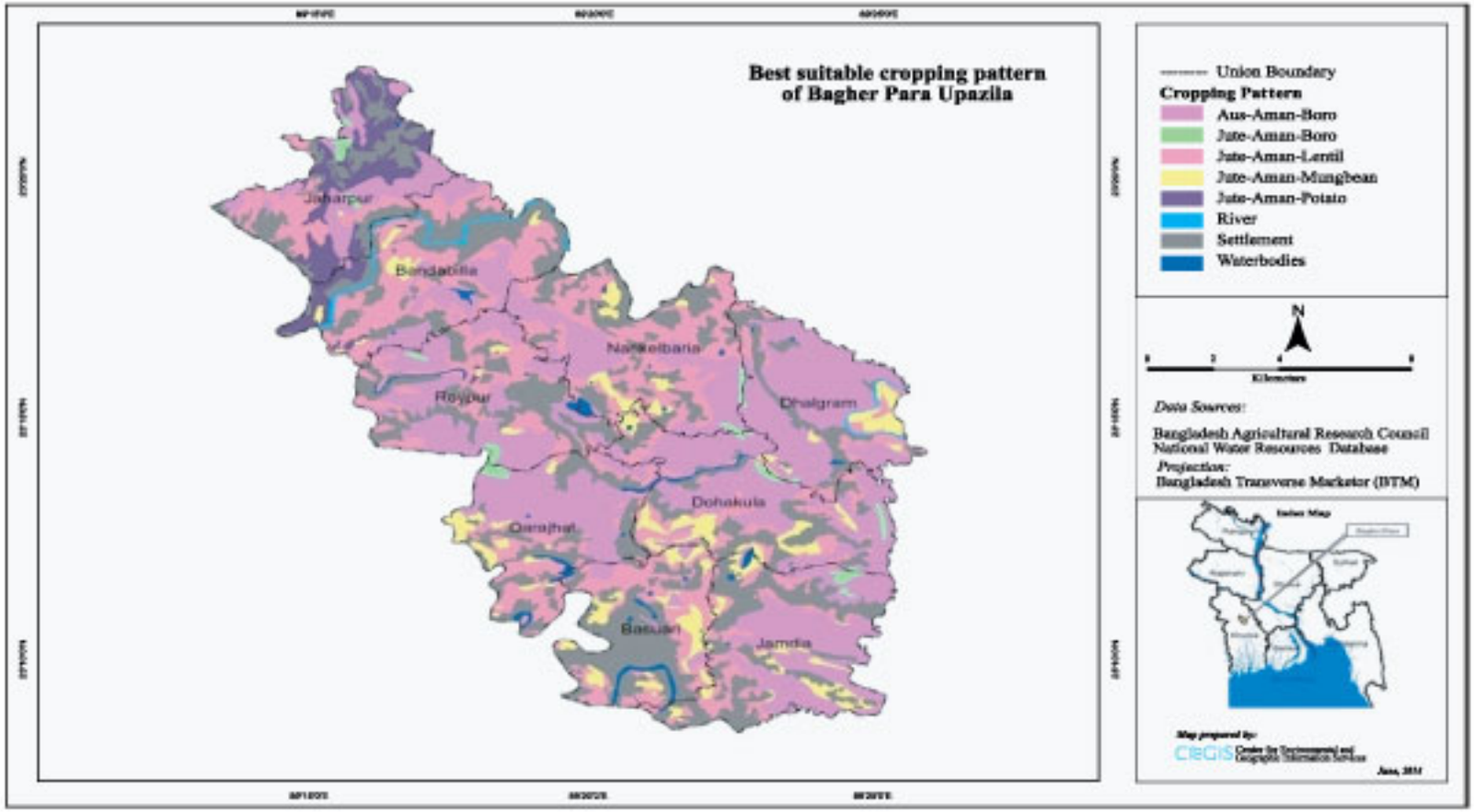
Appendix Figure 7. Satellite Image (A) and Landuse Map (B) of Nachole Upazila



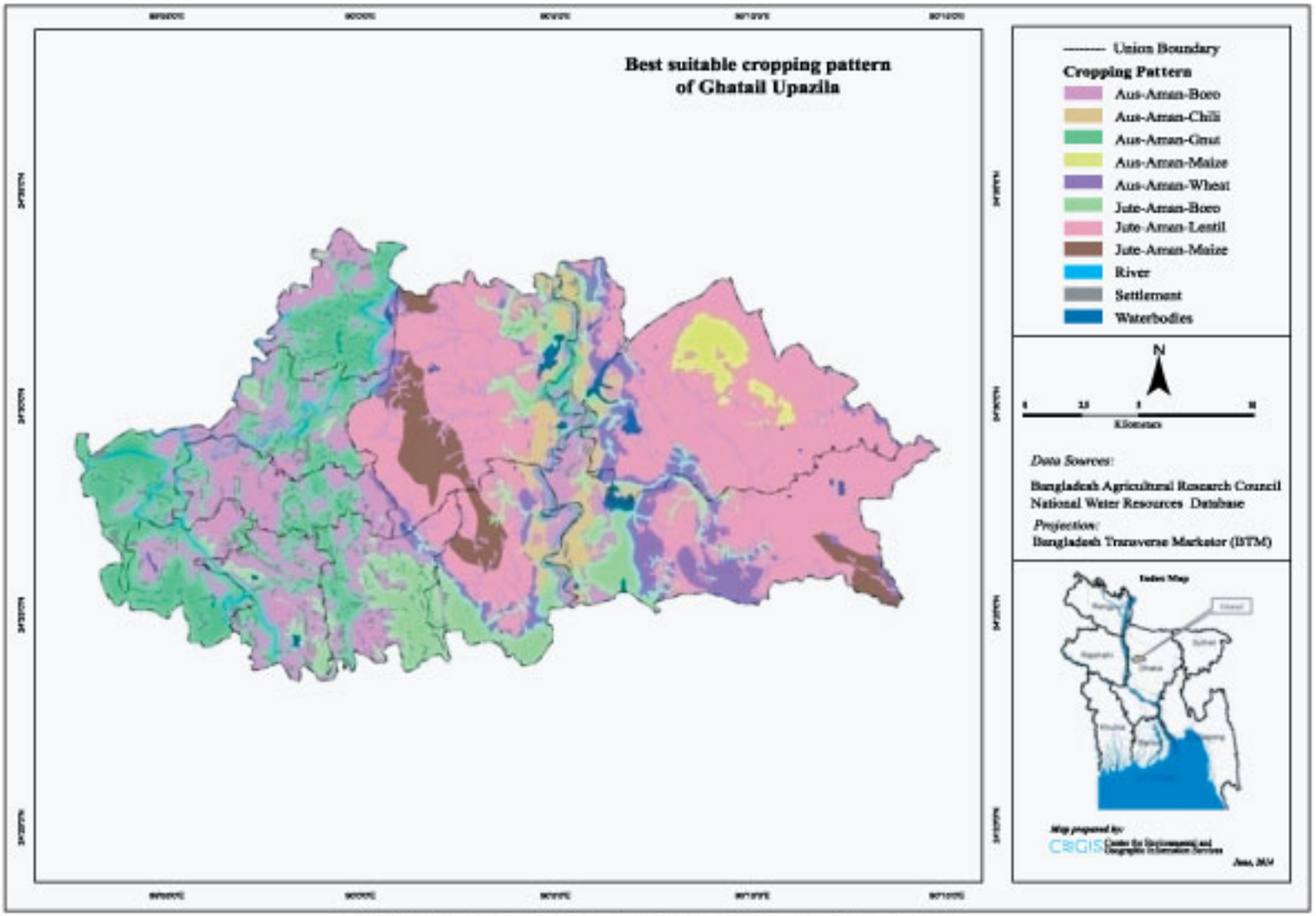
Appendix Figure 8. Satellite Image (A) and Landuse Map (B) of Nakla Upazila



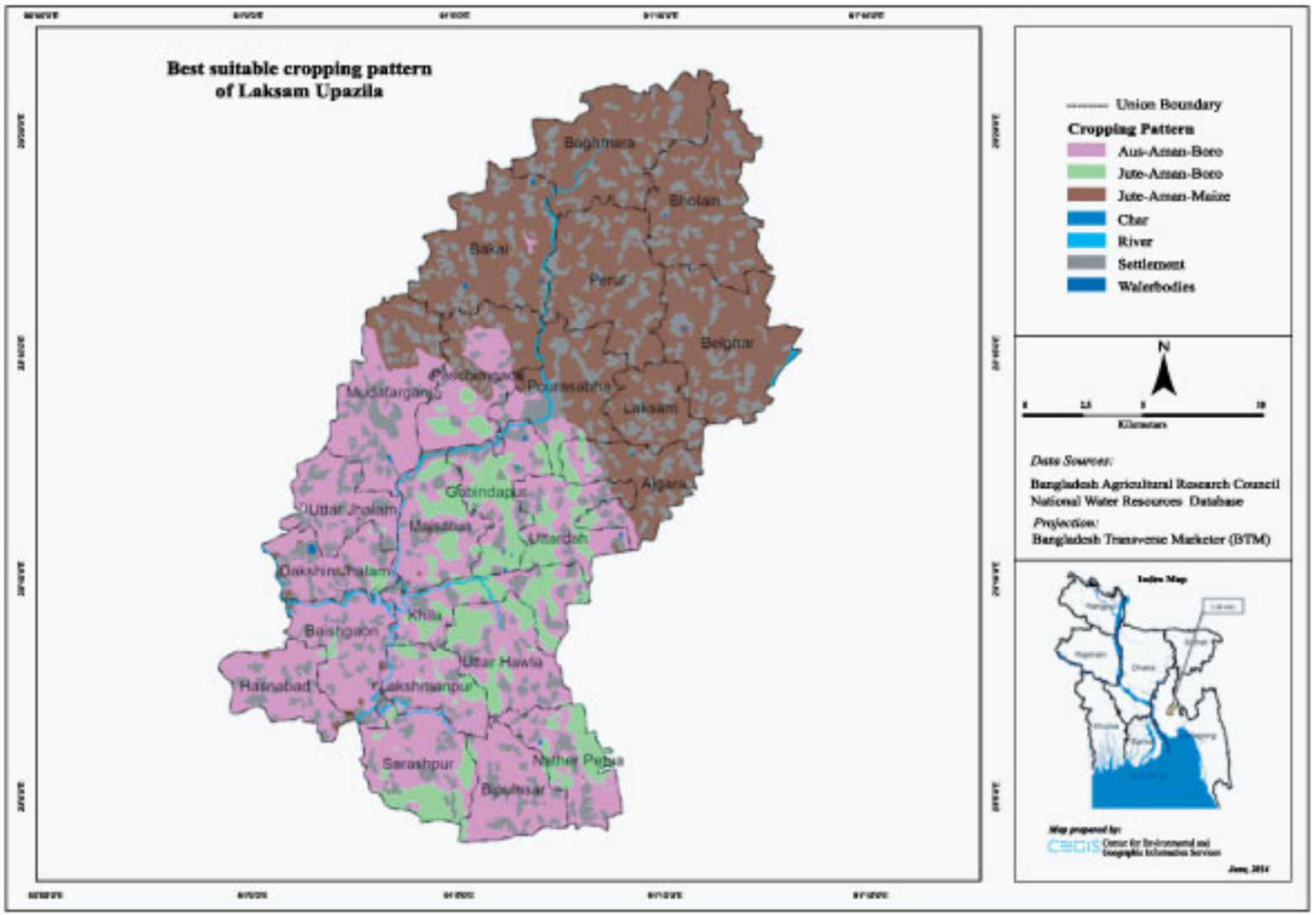
Appendix Figure 9. Satellite Image (A) and Landuse Map (B) of Noakhali Sadar Upazila



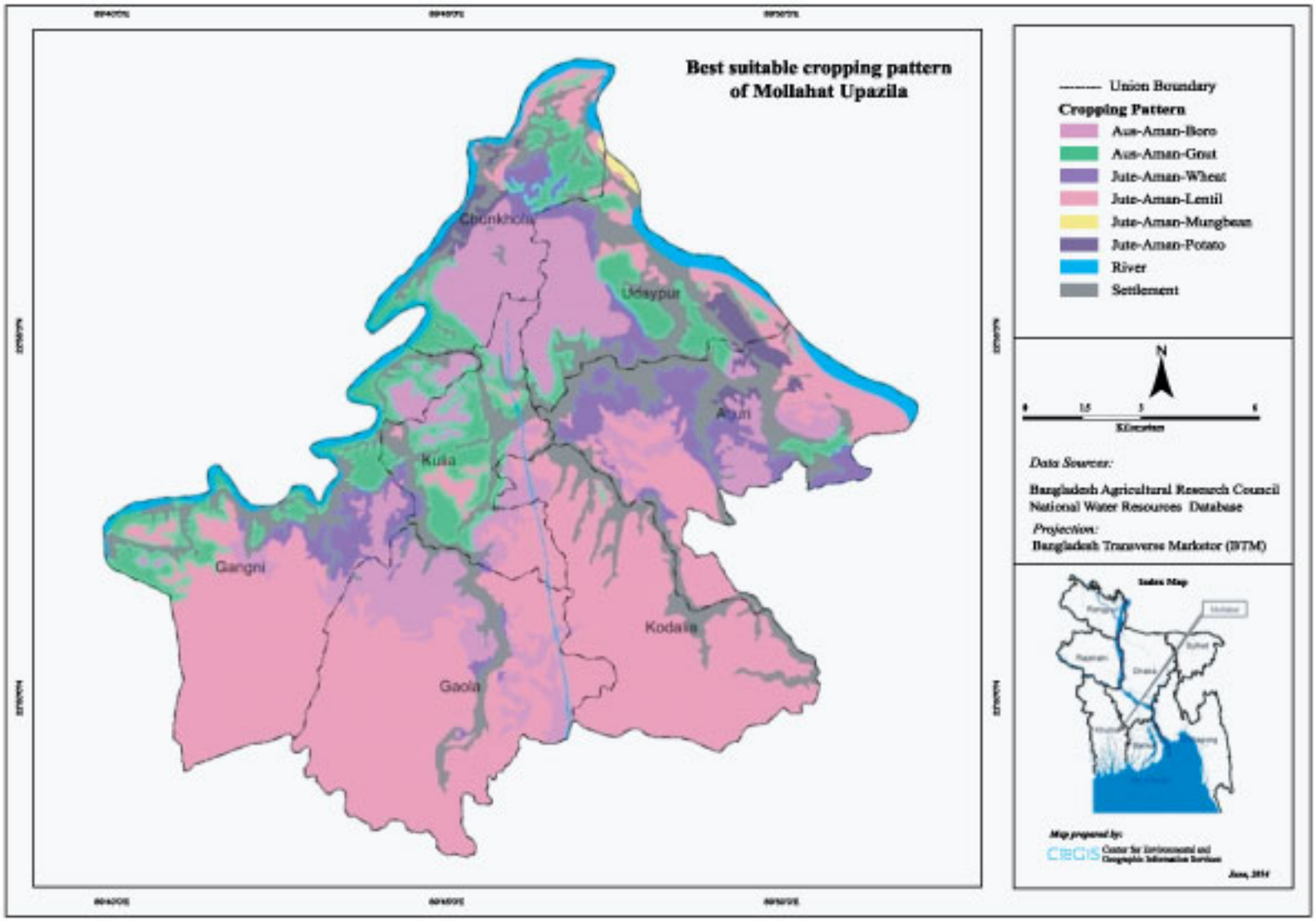
Appendix Figure 10. Best Suitable Cropping Patterns of Bagher Para Upazila



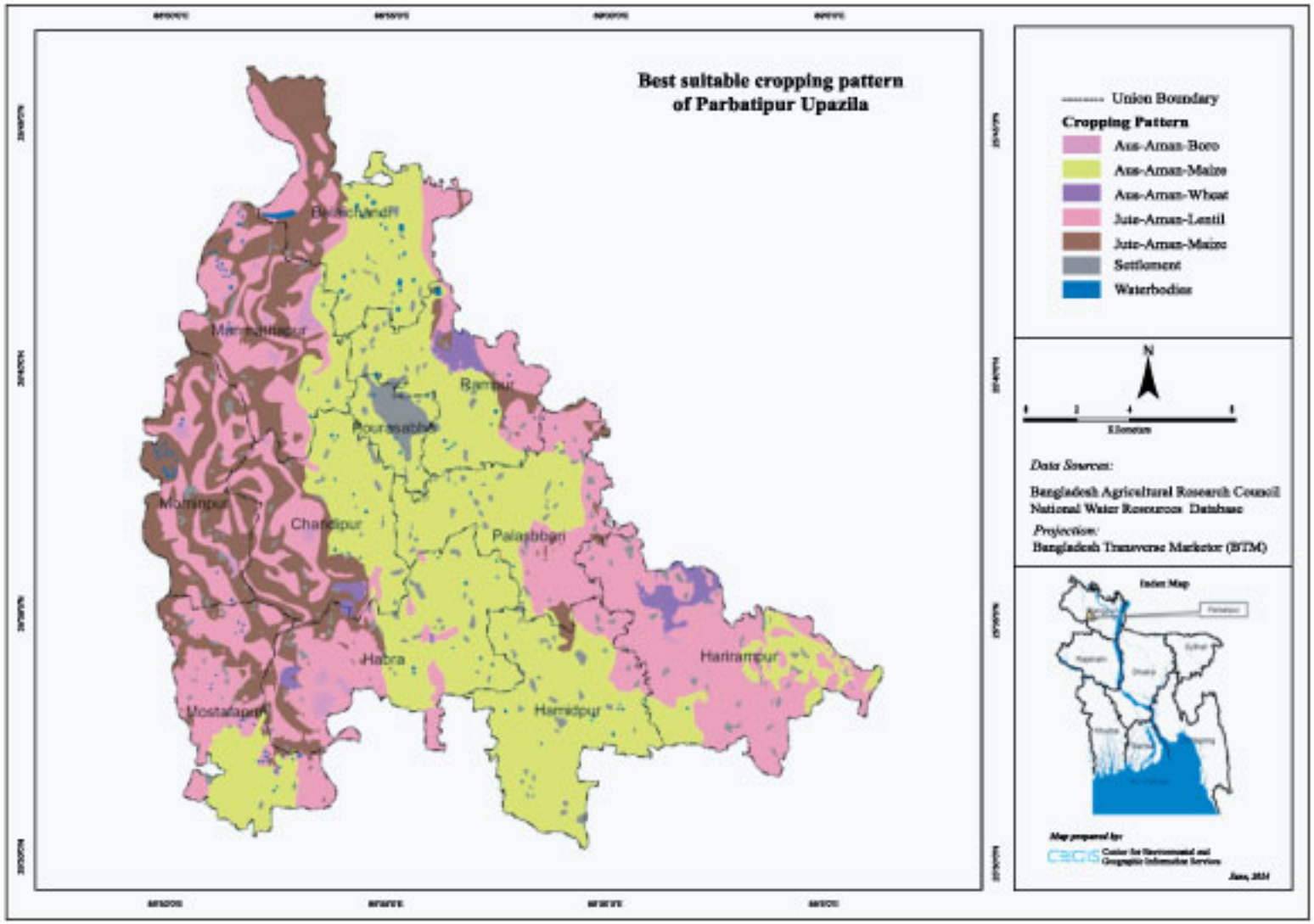
Appendix Figure 11. Best Suitable Cropping Patterns of Ghatail Upazila



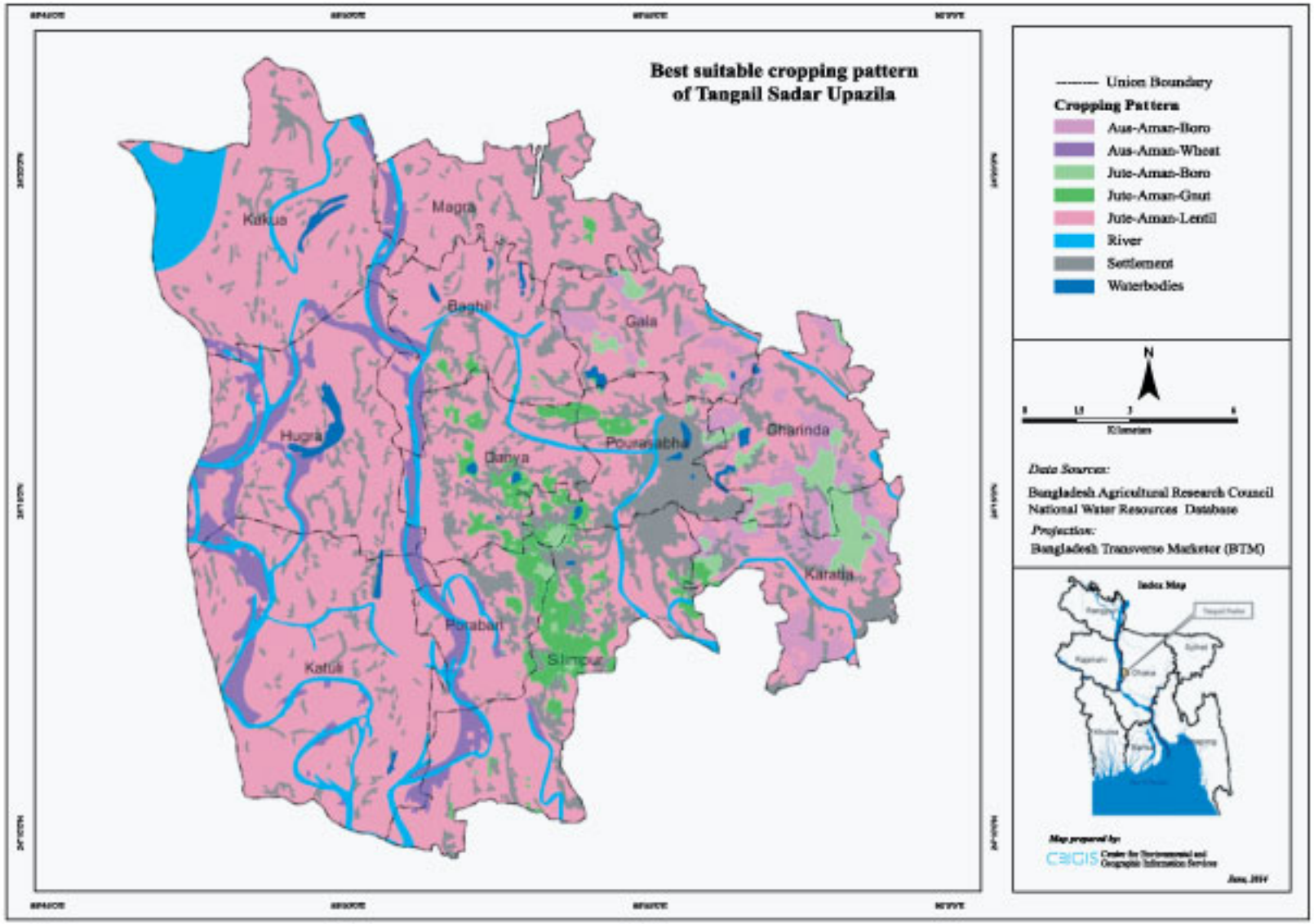
Appendix Figure 12. Best Suitable Cropping Patterns of Laksham Upazila



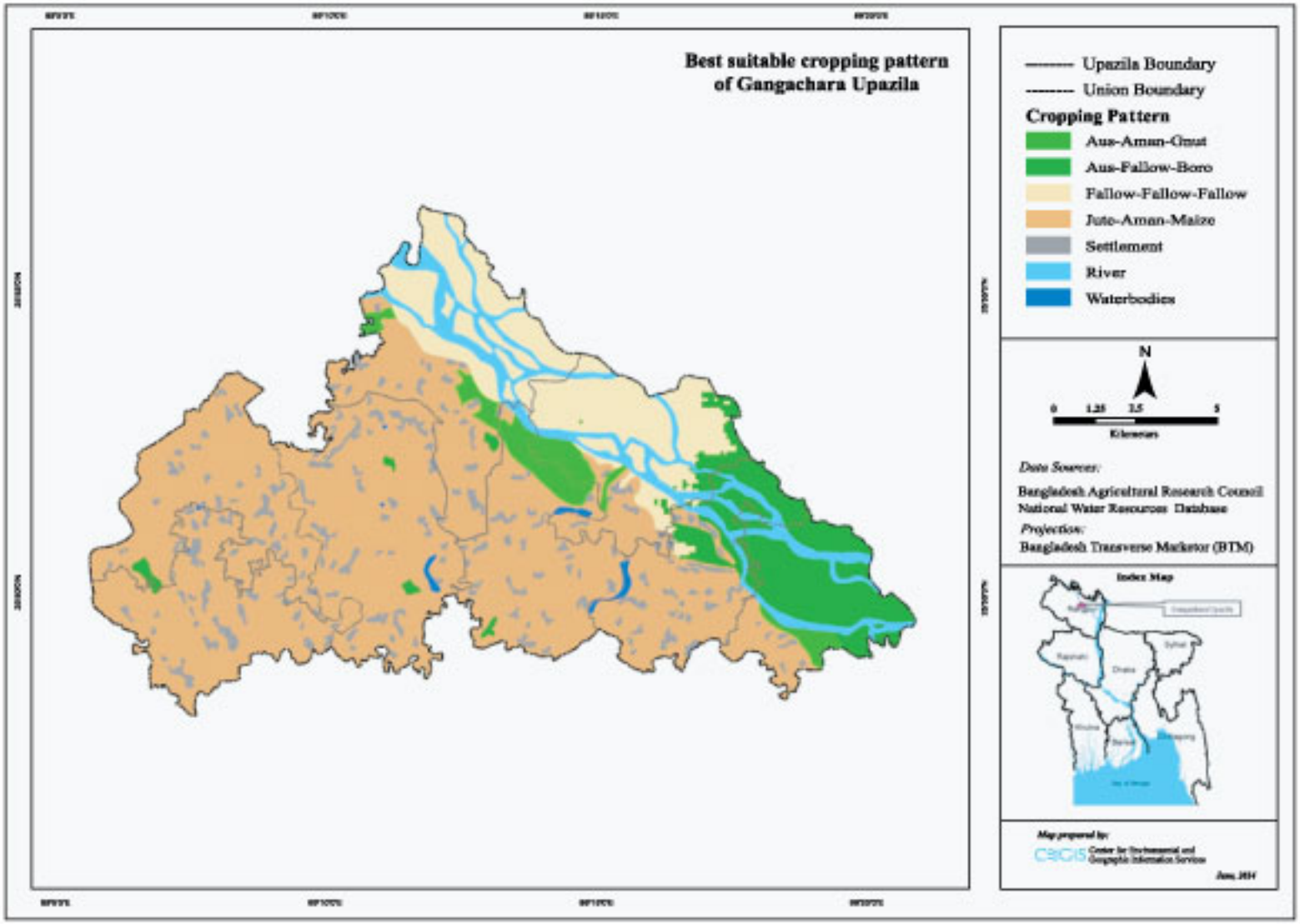
Appendix Figure 13. Best Suitable Cropping Patterns of Mollahat Upazila



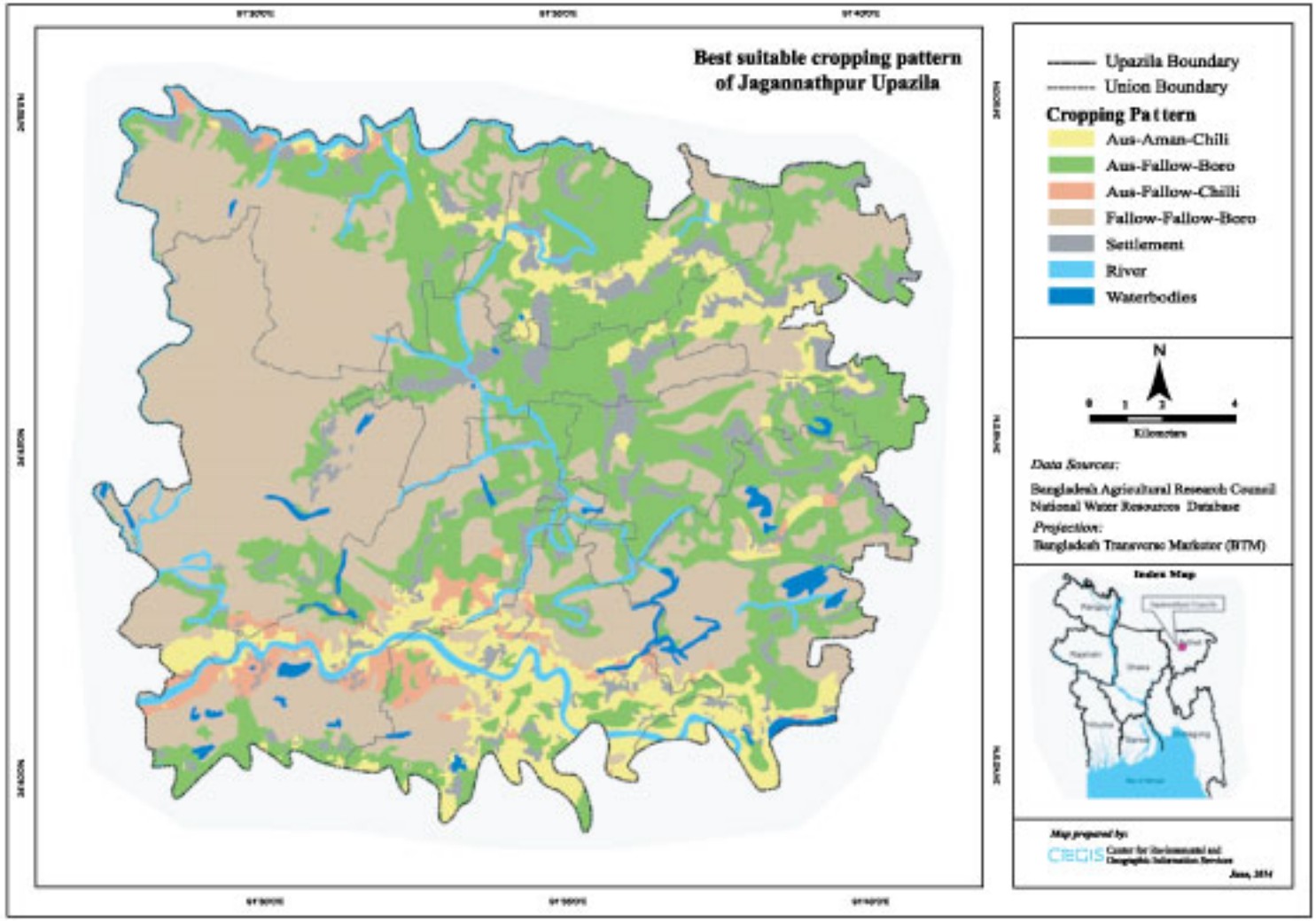
Appendix Figure 14. Best Suitable Cropping Patterns of Parbatipur Upazila



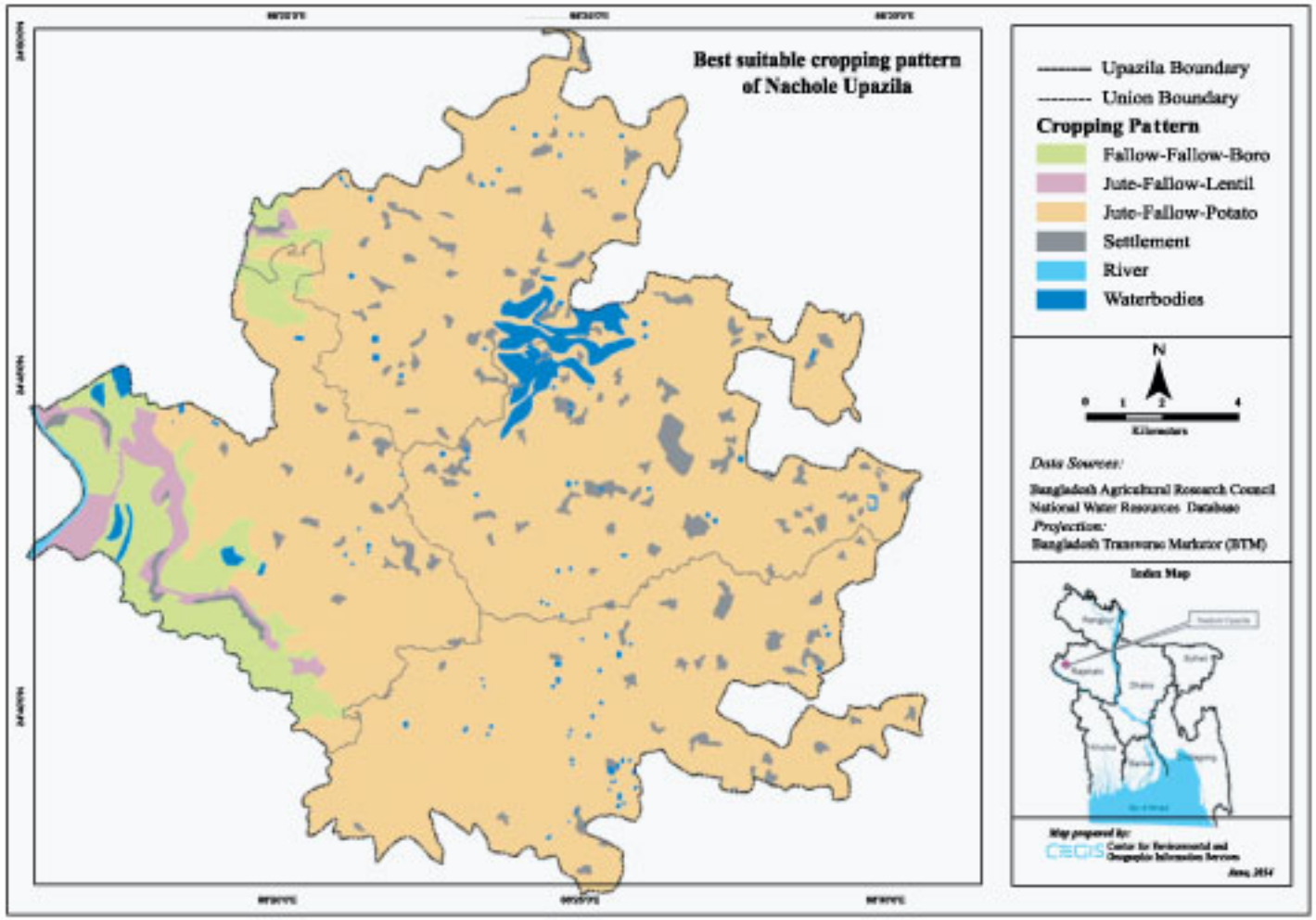
Appendix Figure 15. Best Suitable Cropping Patterns of Tangail Sadar Upazila



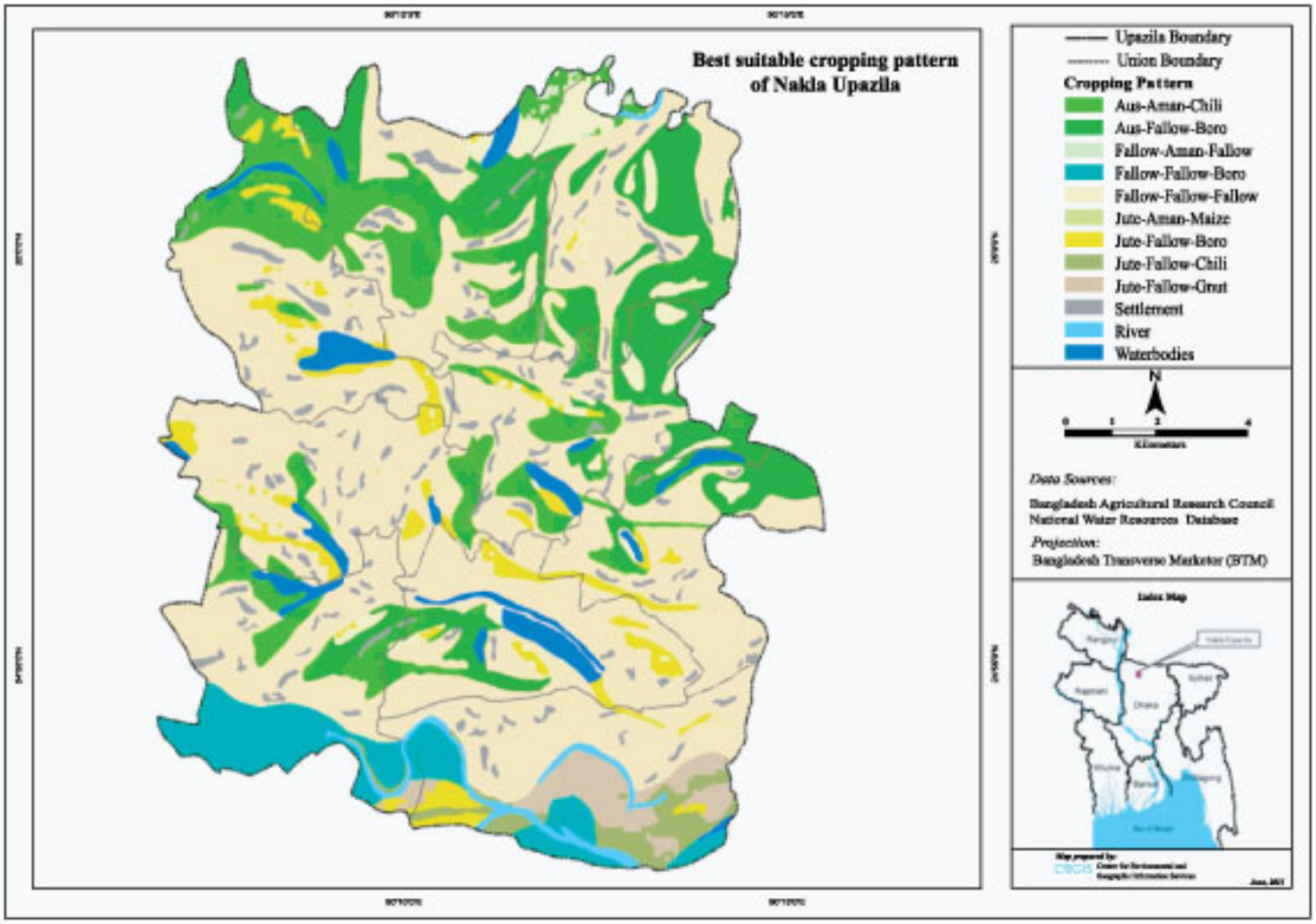
Appendix Figure 16. Best Suitable Cropping Patterns of Gangachara Upazila



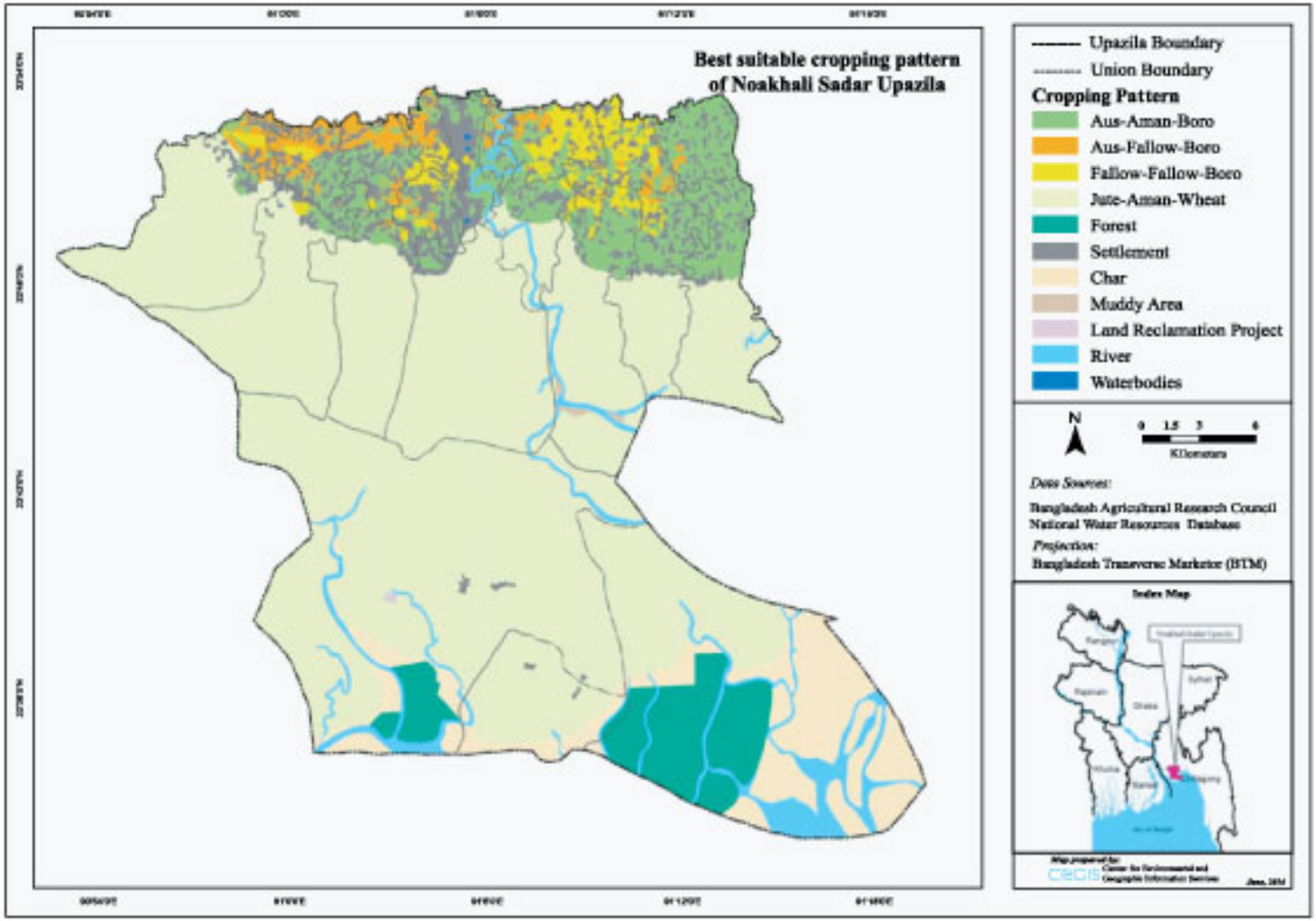
Appendix Figure 17. Best Suitable Cropping Patterns of Jagannathpur Upazila



Appendix Figure 18. Best Suitable Cropping Patterns of Nachole Upazila



Appendix Figure 19. Best Suitable Cropping Patterns of Nakla Upazila



Appendix Figure 20. Best Suitable Cropping Patterns of Noakhali Upazila